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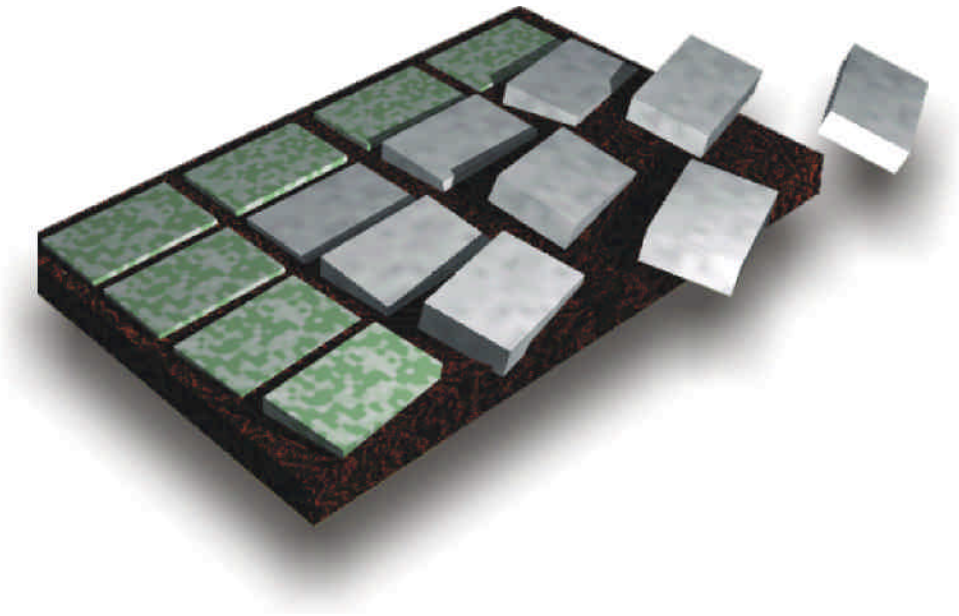

PROLOGA v.5

PROcedural LOGic Analyzer 5.2

USER'S MANUAL

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1. Introduction

1.1. About Prologa

The **Prologa** (PROcedural LOGic Analyzer) system is an interactive design tool for computer-supported construction and manipulation of decision tables.
The system not only supports the manual design techniques, but also offers additional features to enhance the construction, manipulation and validation of decision tables.

Other tools for the construction of decision tables are usually column oriented. They allow the user to generate an empty decision table and then to fill in the columns one by one. These systems may ensure/check for combinatorial completeness, consistency and/or non-redundancy, but offer little or no *help in the design process* itself. **Prologa**, being rule based, does not bear these inadequacies.

The **Prologa** software is written in **Borland Delphi** and runs on Windows 98, NT, 2000 and XP.

Version 5 adds the following features to the previous versions:

- Totally redesigned user interface;
- Import from Microsoft Excel;
- Improved database functionality;
- Intelligent project editing;
- Fuzzy decision tables.

New in 5.2:

- Improved consultation environment
  Dockable windows have been included in the consultation environment, to improve its customizability. Also, parts of the original engine have been redesigned internally;
- XML Import/export
  We have provided an XML-format for **Prologa** decision tables: one can now import a table from or export it to this new file format. (see http://www.econ.kuleuven.ac.be/tew/academic/infosys/research/prologa/decisiontable.xsd)

New in 5.1:

- New and improved export functions:
  Prologa now also supports code generation to Java, C and Eiffel. Also, a prototype version is included that allows you to export a decision table into an MS Word table;
- View as Tree:
  One can now view decision tables in a hierarchical tree format (use the upper left button in the decision table editor window).

Previous versions of the **Prologa** software include:

v. 1.0 : DOS-version
v. 2.0 : DOS-version, extended user interface
v. 3.0 : Windows 3.x version
v. 4.0 : Windows 95 & NT version

1.2. Application Experiences

The decision table workbench **Prologa** has been used in a large number of applications and environments. Some examples of the more common areas of experience:

- *verification and visualization of legal procedures*;
- *checking consistency in medical treatments*;
- *help desk applications for computer networks*;
- *validation of knowledge based systems*;
- *modeling and verification of complex procedural decision situations in general*;
- *information systems analysis, descriptions of systems requirements and software engineering*;
- *rates and premiums in banks, insurance companies*;
- *checking technical specifications in manufacturing*;
- *generating test cases for program structures*.

Besides the classical arguments for the use of decision tables (easy checking for completeness, consistency and correctness), a number of less known advantages have been revealed by these experiences: good communication facilities with the end user, full life cycle support, implementation independence, ease of translation, ...

1.3. Using this manual

This manual has been written for both users experienced with the practice of decision tables and novices to the topic. Therefore, this manual will not only explain **Prologa**, but will also deal with the theory of building decision tables and with the way to represent the gathered knowledge.

This manual is split into 3 parts:

The first part explains the **Prologa** system and shows examples of a **Prologa** session.

The second part will treat the concept of decision tables and the description of the knowledge specification language for decision tables. The emphasis will be on the differences between the conventional view on decision tables and the form that is adopted here.

Finally the third part consists of a reference manual which deals with various commands, shortcuts, limitations and hints and the relations between the different export facilities and other systems.

2. The Prologa System

This chapter is the core of the User's guide. It explains most of the functions of **Prologa** and shows when to use them. It also shows the advantages and limitations of the system, and explains what a **Prologa** session should look like.

2.1. A Short Introduction to Decision Tables

Even if at first sight decision tables in their current form look almost the same as years ago, their use has changed a lot. A decision table is a tabular representation of a *decision situation*, where the state of a number of conditions determines the execution of a set of actions. Not just any representation, however, but one in which all distinct situations are shown as columns in a table, such that every possible case is included in one and only one column (completeness and exclusivity). An example of a decision table is presented in Figure 2-1.

1. Quantity Ordered (Q)	Q<10	10<=Q<15			Q>=15
2. Travel Distance (D)	-	D<50	50<=D<100	D>=100	-
1. No Discount	x	-	-	-	-
2. Discount 2 %	-	-	-	x	-
3. Discount 5 %	-	-	x	-	-
4. Discount 10 %	-	x	-	-	x
5. Railway Transport	-	-	-	-	x
6. Road	x	x	x	x	-
7. Bill Type A	x	x	x	x	-
8. Bill Type B	-	-	-	-	x

Figure 2-1. Example of a Decision Table

The tabular representation of the decision situation is characterized by the separation between conditions (top) and actions (bottom), on one hand, and between subjects (left) and conditional expressions (right), on the other.

Every table column (decision column) indicates which actions should (or should not) be executed for a specific combination of condition states. A column then contains a state for each condition

or a contraction of states which yield the same result (with possibly "irrelevant" ("-") if this is the case for all states of that condition), followed by the resulting value for each action. The condition oriented approach of the decision table makes it very useful to *display* knowledge, with such advantages as : overview, readability, easy checking for consistency and completeness.

The order of the columns shows that only *single hit tables* are taken into account, in other words, each situation is present in only one column and, consequently, the columns will not interfere with each other. This excludes the use of the so called *multiple hit* tables, where a particular situation can be present in several (partially overlapping) columns, such that the order of the columns determines the decision logic, which strongly reduces the overview and the validation possibilities.

If each column only contains simple states (no contractions or irrelevant conditions), the table is called an *expanded* decision table (*canonical form*), in the other case the table is called a *contracted* decision table (*consolidated form*). The transition from one form to the other is defined as *expansion* (*rule expansion*) and *contraction* (*consolidation*).

2.2. Getting Started with Prologa

The construction of decision tables is a creative activity but it contains several routine actions which are quite time-consuming. This chapter deals with automating the construction of decision tables, which will be discussed in detail.

2.2.1. A Guide through Prologa

Decision tables in **Prologa** are organized in projects. A **project** contains one or more (possibly related) decision tables and supplementary information about the tables. The project information is stored in a relational database (*ProjectName.MDB*) and in a number of decision table files (*DecisionTableName.TAB*).

Although it is possible in Prologa to create and edit tables without using a project (for historical reasons), this is not recommended, as a lot of manipulations are only available at the project level, not at the table level.

When building each individual decision table, the user should essentially provide the system with the following information : a list of *conditions* with their *states*, a list of *actions* and a list of *relations between condition states and actions* (in the form of logical expressions or rules). This enables the system to construct and display the corresponding decision table.

Constructing a decision table is an iterative process, where the ability should be given to make corrections and refinements in an interactive way. For this purpose a flexible dialogue structure has been provided, containing a.o. the following major steps:

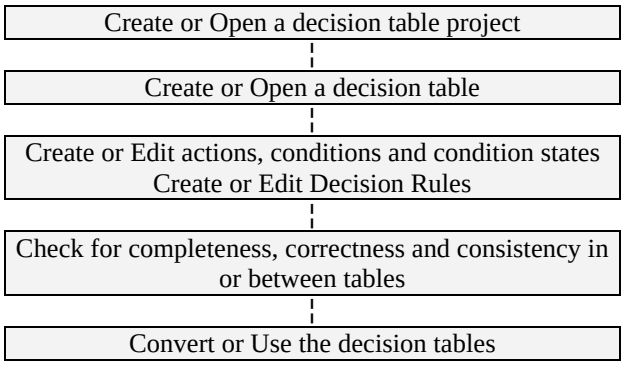

Create or Open a decision table project
Create or Open a decision table
Create or Edit actions, conditions and condition states
Create or Edit Decision Rules
Check for completeness, correctness and consistency in or between tables
Convert or Use the decision tables

Figure 2-2. Major steps in Prologa

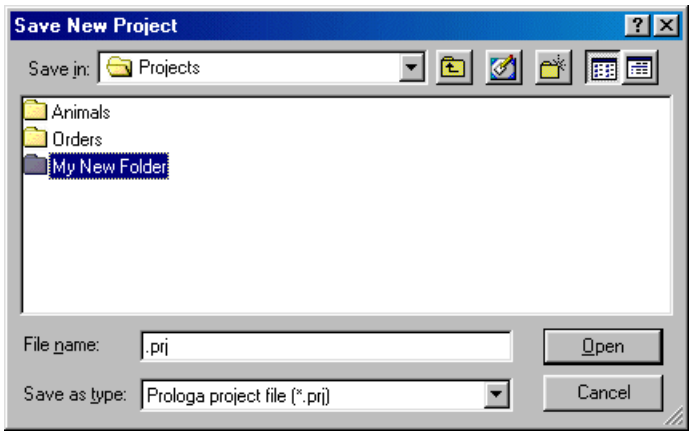
2.2.2. Basic Functions of the Prologa system

In this section, we will start by explaining each basic function. In another chapter you will find complete examples of the underlying Knowledge Acquisition, Knowledge Structuring and Validation cycle.

2.2.2.1. Create or Open Project

Select the File menu and choose New Project or Open Project. As a project will contain a number of related files, it is good practice to use a specific (new) folder for every project.

Create New Project



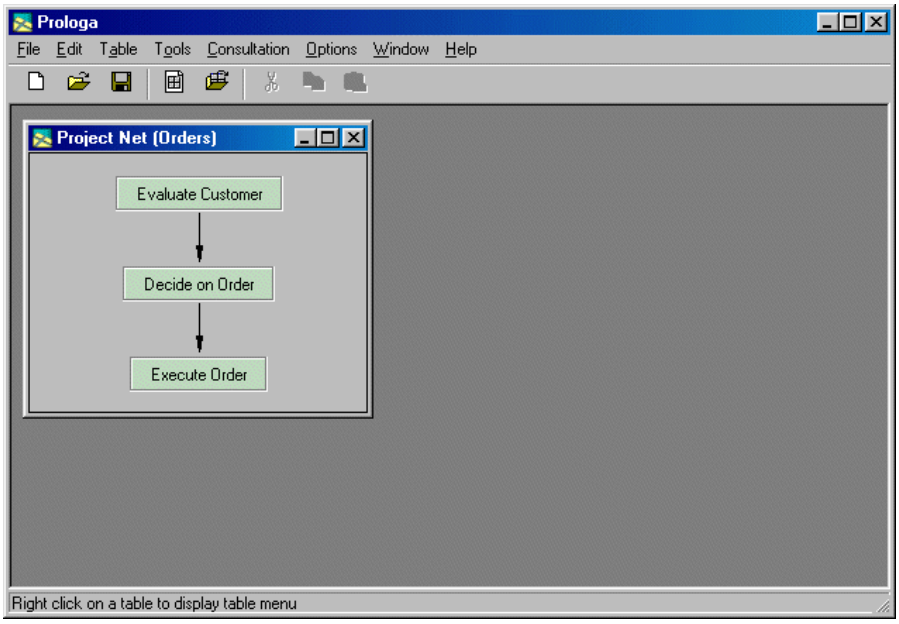
A project is a collection or knowledge base of related decision tables. For each project, there is an MS Access database file into which all kinds of information is stored. For instance, information about prompts, help notes, etc. that is used for consultation purposes is stored here.

Why use projects and not just work with separate tables?

- file management is handled by **Prologa**
- the consultation environment only works with projects
- additional functionality is available in projects, such as intertabular verification, direct linking between tables and automatic updating.

Open Existing Project

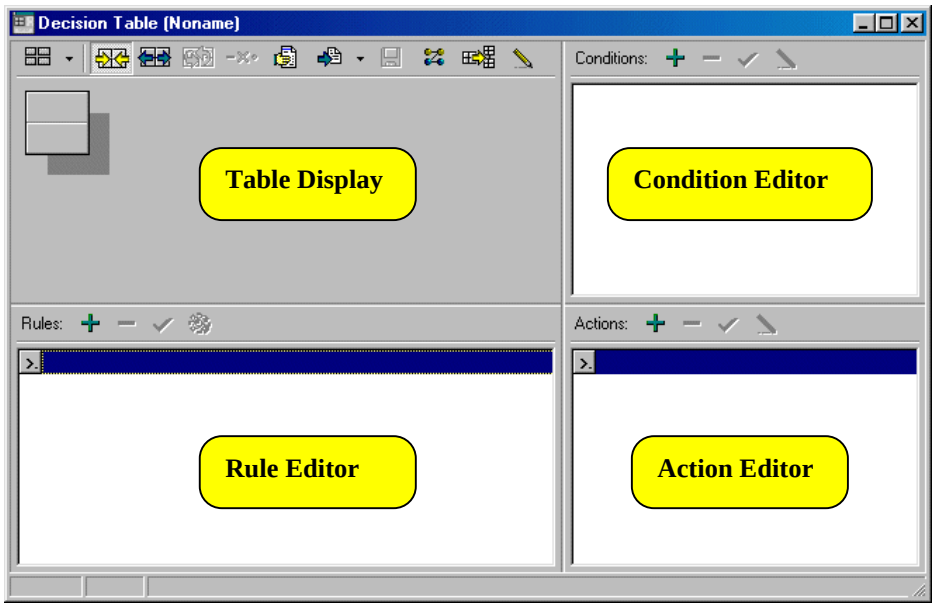
Choose e.g. the orders example from the distribution disk and select the project (orders.prj). The project window appears, showing the relation between tables in the project. Double-click a table to open it.


Prologa
File Edit Table Tools Consultation Options Window Help
Project Net (Orders)
Evaluate Customer
Decide on Order
Execute Order
Right click on a table to display table menu

2.2.2.2. Create or Open Table

Once a (new) project is started, you can begin working with a decision table by selecting the File menu and choosing the New Table command or Open Table command.

The decision table window then allows you to work with this table. The decision table window consists of 4 parts:

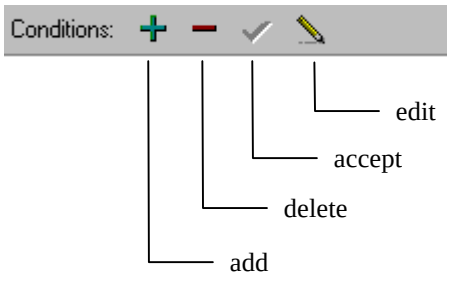


2.2.2.3. Editing the Decision Table

The decision table is specified using conditions and condition states, actions and decision rules.

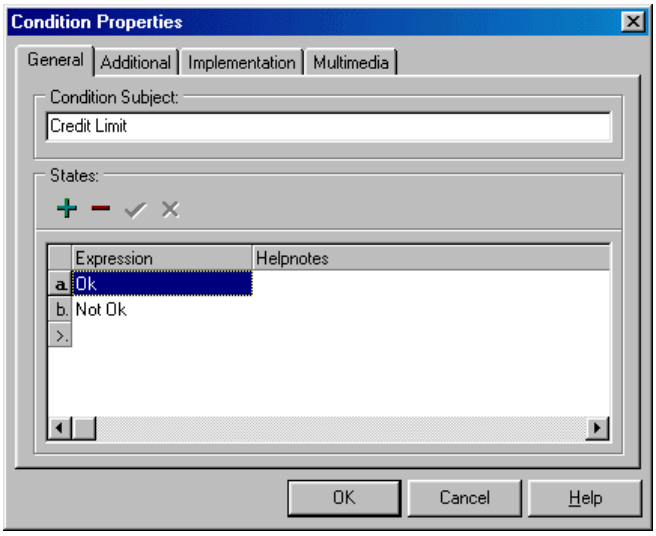
Editing conditions and actions

Conditions and actions constitute the major elements of the decision table. The number of conditions, condition states and actions that can be entered is limited. If there is a need for more conditions or actions, it is usually an indication that the problem is too complex to model in one single table and table structures might be useful.



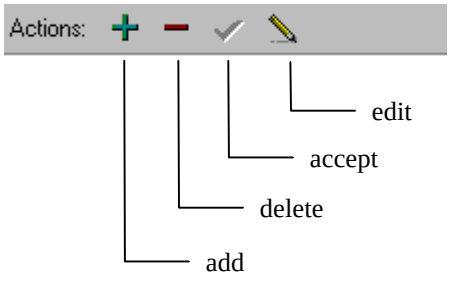
Conditions and actions can be added (plus button), removed (minus button) edited (edit button), reordered (drag & drop a condition to its new position in the list or in the decision table). Conditions and actions can only be removed if they are not used in a decision rule.
Names (e.g. of conditions, condition states or actions) are not case-sensitive in **Prologa**.

Condition subjects (e.g. color) and states (e.g. red, blue, etc.) are entered in a separate form.



A total of 9 conditions can be entered, with a maximum of 9 states for each condition. Due to memory limitations, the total number of state combinations, which is equal to the maximal number of columns of the expanded decision table, is limited to 4096.

Actions can be edited directly on the action grid (press enter or ✓-button to end editing state).
A total of 20 actions can be entered.



Editing decision rules

In **Prologa**, the decision logic can be specified in two ways: by using *decision rules* or by clicking action entries directly in the table display (*fill by mouse*). The fill by mouse option is meant for fine-tuning, but in most cases it is more rewarding to use decision rules. The decision table logic is then entered by specifying rules connecting actions and combinations of condition states.
When decision rules are added or modified, the table display is always kept up-to-date.

In order to minimize keyboard input when entering decision rules, conditions and actions are referred to by their sequence number (1, 2, 3, …) in the condition and action editor. Condition states are indicated with their letters (a, b, c, …). *1a* therefore means *state a* of *condition 1*.

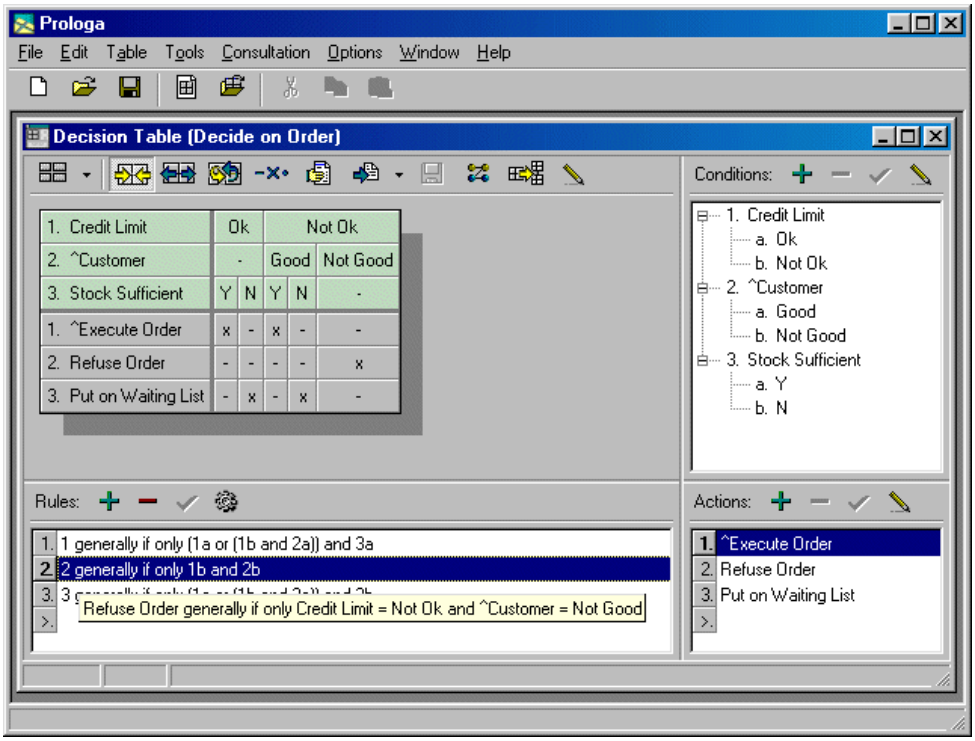


Figure 2-3. Entering decision rules

Examples:

rule 1 : *1 generally if 1a*

If condition 1 has state a, action 1 is true.
Hint : just enter 1 if 1a, **Prologa** will automatically add the "generally" token.

rule 2 : *Not 1 generally if 1a and (2b or 3acd)*

If condition 1 has state a, and condition 2 has state b or condition 3 has state a, c or d, then action 1 is false.
(partially overrides rule 1)

rule 3 : *Not 1 definitely if 1b*

If condition 1 has state b, action 1 is false.
("definitely" means that the entries cannot be overridden by another rule)

For some other constructs, look at the example tables shipped with **Prologa**.

Syntax:

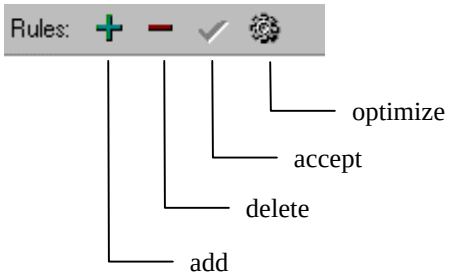
A decision rule consists of an action-part, an if-part and a condition-part, in this order. In the following table, the syntax is split in three parts, each part is represented in a column. The operators (with their internal notation) are listed in descending order of priority.

ACTION PART		IF PART		CONDITION PART	
Impossible	: /	1. dif (definitely if)	: **!**	always : #	1. **( )**
all	: **@**	2. if (generally if)	: **:**		2. not : **-**
		3. pif (possibly if)	: **?**	**0..9**	3. and : *****
1..9				**a..f**	minus : \
				rule : **.**	nand : **$**
1. not	: **-**				4. or : **+**
2. and	: *****				xor : **&**
2. only	: |				nor : **%**
					5. only : |

Figure 2-4. Elements of a decision rule

The complete decision table language behind this syntax, is described elsewhere in the manual.

Brief overview:



Rules can be edited directly on the rules grid. Rules can be reordered using drag & drop.

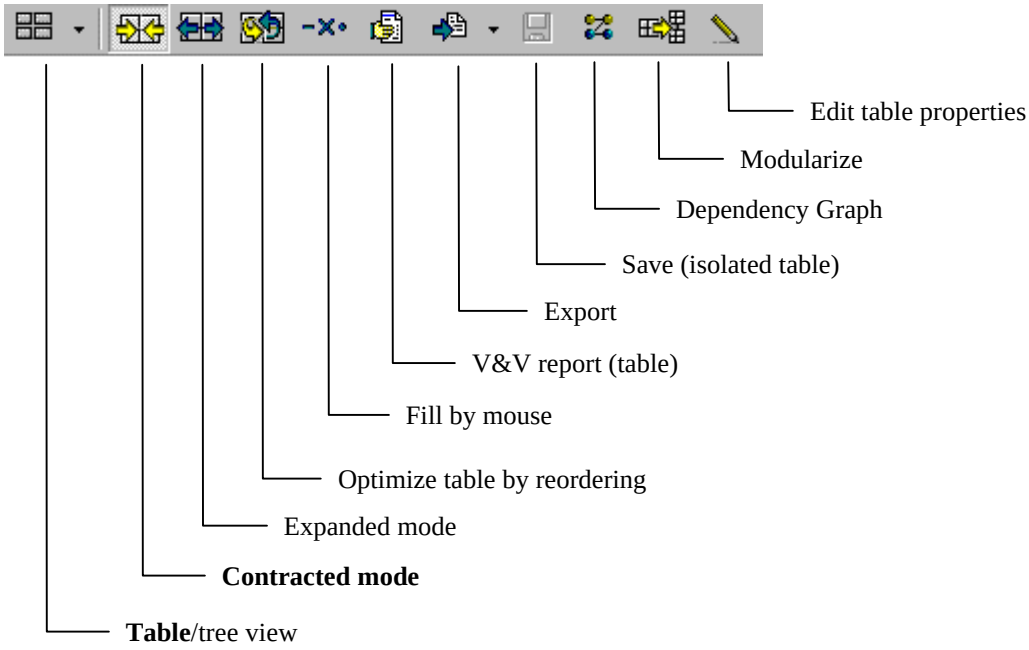
There are three types of decision rules (with corresponding table entries):
1. *Definite rules*: can not be overwritten. Trying to overwrite a definite entry with an opposite definite entry will trigger a contradiction warning;

2. *General rules*: allowing to specify default rules, exceptions to the default rules, a.s.o. The order of the rules is important as overriding entries is possible.
3. *Possible rules*: this type is only used to express rules of the form: action x is only possible if …, meaning that action x is not to be executed in all other cases.

A button in the rule editor (optimize rules) allows to recreate (minimal) rules from the current table logic. This can be interesting if the table was created using a lot of simple rules (e.g. using fill by mouse). The optimize rules option basically produces one rule for each action. Use this option with caution (and only after saving the table) as it destroys the original decision rules.

Note that the number of decision rules is limited (currently, about 126 rules can be entered). A second limitation is that the rules, as they are stored in the internal decision grid chart, cannot contain more than 1024 simple elements. (See also the section on Limitations & Hints.)

The table display



While (or after) editing conditions, actions and rules, the table display always offers an up-to-date view on the decision table. The table can be shown in different ways and starting from the table a number of manipulations can be performed.

View as table/tree

In some cases it might be interesting to view the decision table as a tree (or export the tree structure to a file). The tree view also contains some options as indicated in Figure 2-5.

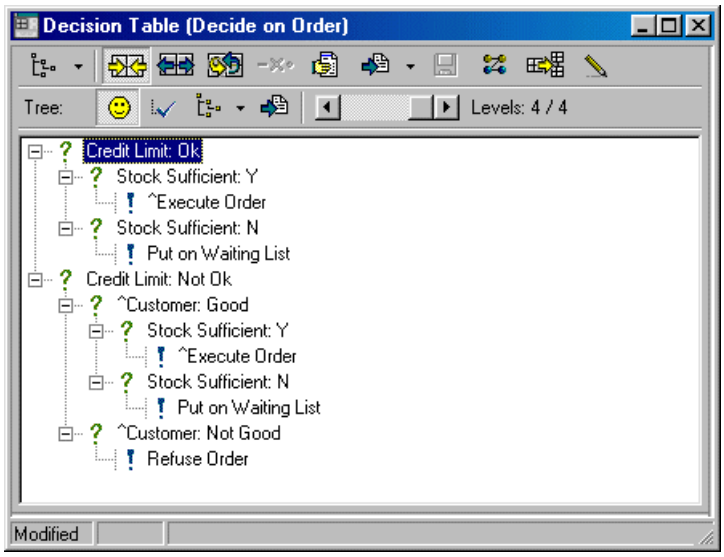


Figure 2-5. View table as tree

Selecting the appropriate Table View

By default the **contracted** table is shown, because it is more compact. For validation or fill by mouse purposes, it might be interesting to temporarily switch to the **expanded** table view.

The number of columns in a decision table, however, can not only be reduced by contracting the table. The order in which the conditions appear in the decision table may have a strong influence on the number of columns the contracted table will contain. **Prologa** can help you to set the optimal order of these conditions such that the size of the decision table will be reduced to a minimum. Impossible condition orders can be excluded from the evaluation by imposing precedence constraints. When you activate **Optimize Order**, all possible orders will be evaluated. You can then choose one of the suggested condition orders.

The first step is to calculate the number of feasible condition orders. This number will depend on the number of conditions and the restrictions on their order (sometimes condition X has to be tested before condition Y). The second step **Prologa** will take is the generation of all feasible orders (*list of feasible condition orders*) where the order resulting in the smallest number of columns will be retained.

Fill table by mouse

By setting a table into "fill table" mode, one can fill in individual table entries by mouse in order to complete or adjust the table.

Clicking on a '.' or '-' produces a 'x', while clicking on a 'x' reverses it into a '-'. Every update leads to a 'generally if' decision rule which is added automatically. Definite entries cannot be changed because of their higher priority and because overriding is not allowed.

Switch off the “fill table” mode after editing in order to update the table display. While “fill table” mode is on, some table operations are not possible before it is switched off again.

2.2.2.4. Validation & Verification (V&V)

Two verification & validation (V&V) reports are provided in **Prologa**: the (intra)tabular report indicates problems within a single table, while the intertabular V&V report analyzes the relations between different tables in the same project.

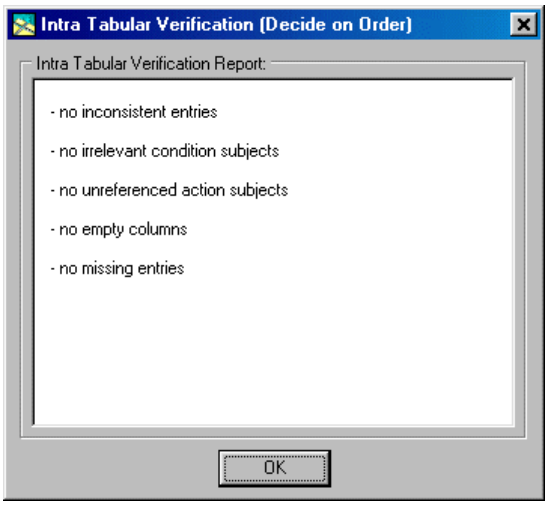

Intra Tabular Verification (Decide on Order)
Intra Tabular Verification Report:
- no inconsistent entries
- no irrelevant condition subjects
- no unreferenced action subjects
- no empty columns
- no missing entries
OK

Figure 2-6. IntraTabular V&V report

2.2.2.5. Export Options

Prologa can generate various other representations, that can then be saved as a text file, copied to the clipboard, etc. . Figure 2-7 provides you with an overview of the commands in the Export Submenu and the export files they generate.

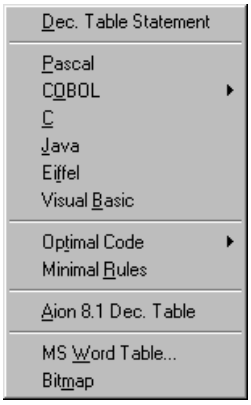


Figure 2-7. Export Commands & Files

Generate Code

In some cases decision tables are designed to be converted to executable program code. The code can be a *straightforward* translation of the columns of the (contracted) decision table, or it can be *optimized* for execution efficiency by generating the optimal execution tree.

When generating code, **Prologa** will start from the contracted table. All non-positive action entries ('-', '.' and '?') are converted into '-' (do not execute). Subtables are indicated, but are not included in the code. The resulting code is represented as a nested IF THEN ELSE statement.

A straightforward translation is provided for common programming languages.

PASCAL, C, JAVA, Visual Basic, ...

The generated program code will only give the structure of the resulting *if-then-else*-statement (according to the syntax of the language). To obtain executable program code, I/O-statements and declarations will have to be added. Moreover, the names of conditions, condition states and actions must correspond to the language syntax. Even if the decision table is simply converted

from left to right and from top to bottom into nested if-then-else structures (without further optimization), usability of code is quite high, as minimal execution time is not always the most important issue.

COBOL

COBOL code can be generated in two ways: as *if-then-else*-statements or using the EVALUATE statement.
The EVALUATE statement, as it was defined in ISO COBOL 85, is an attempt to include decision tables in COBOL. When generated from **Prologa,** it is much easier to construct the statement. The generated code is a straightforward left to right translation of the decision table (with one WHEN clause for each table column).

Optimal Code

A lot of research on decision tables has been about generating optimal programs, taking into consideration condition test times and column frequencies. This means that in different paths of the execution tree, conditions are not necessarily tested in the same order. In each branch of the tree, the most decisive condition will be examined first, thereby minimizing execution time of the decision process.
The problem of optimal conversion is not treated extensively in **Prologa,** as it was not meant for programming purposes in the first place. What **Prologa** can do, however, is generate a (near) optimal execution tree in the same common programming languages. Condition test times and column frequencies are considered equal. Precedence constraints between conditions are not taken into account.

Generate Decision table Statement

The decision table statement is a short notation containing all elements of the decision table (conditions, actions and rules), much like the **Prologa** table file, but without the internal data structures.

Example:

```
DECTABLE
COND 1: Age Of Account : < 1 Year, >= 1 Year;
     2: Annual Amount (T) : < 1, >= 1 - < 5, >= 5;

ACT 1: Customer := Not Good;
    2: Customer := Good;

RULES 1: Only 2 generally if 1a and 2bc or 1b and 2c;
      2: Only 1 generally if not rule 1;
      3: 2 generally if always
END
```

Generate MS-Word Table

The decision table can be exported to an MS-Word table, such that the table elements can easily be manipulated in MS-Word.

Decide on Order					
1. Credit Limit	Ok		Not Ok		
2. Customer	-		Good		Not Good
3. Stock Sufficient	Y	N	Y	N	-
1. ^Execute Order	x	-	x	-	-
2. Refuse Order	-	-	-	-	x
3. Put on Waiting List	-	x	-	x	-
	1	2	3	4	5

Figure 2-8. Export to MS-Word

2.3. Advanced features of Prologa

Prologa has been built as a full decision table engineering workbench, incorporating several possibilities of decision tables. It has advanced features going much further than the automated design of single decision tables. This section explains the working of those features. Examples are given in other chapters.

Some of the features go well beyond simple editing and might involve complex changes in the decision table project or tables. It might be a good idea to save first, in case you are not satisfied with the result and want to undo the entire operation.

2.3.1. Projects and Relations between decision tables

A table can refer to one or more subtables. Subtables can be referred to by multiple tables.

Two kinds of subtables are possible:

- Action subtables will give further details on what additional knowledge holds for certain cases, e.g. what discount to give if an order is accepted (similar to a *procedure* in a programming language);
- Condition subtables will determine the state of a certain condition, e.g. when do you consider someone a good customer? (comparable to a *function* in a programming language).

All subtables are closed tables that will return to the place they were activated from (*no goto's*). Therefore the actions or conditions that are below a subtable call will be executed as well (after executing the subtable).

2.3.1.1. Linking project tables

Relations between tables and subtables are maintained by the project and visualized in the Project Net.

Using a project offers a lot of advantages for linking tables:

- Relations are based on logical table names (for action subtables) and subject names (for condition subtables), as specified in the project;
- The Project Net window is automatically updated;
- If there is no decision table in the project with that specific name, a new table will be automatically created and linked;

- The Consultation environment and Intertabular verification only work with projects, not single tables.

Relations with subtables are **created** by starting the condition or action name with '^'.

Example:

Assume that 'Decide on Order', 'Evaluate Customer' and 'Execute Order' are three tables in an 'Orders' Project.

The 'Decide on Order' table contains a condition '^Customer', which will receive its value in another table. This other table can have any name, as long as at least some of its action subjects read Customer := Good, or some other value.
The 'Decide on Order' table also contains an action '^Execute Order', which refers to the name of an action subtable.

2.3.1.2. Direct linking of tables without a project

In the current **Prologa** version, there is a way of specifying relations between single tables that do not belong to a project.

This facility only exists for historical compatibility reasons and it is not recommended for new developments, as there are a number of limitations:

- Relations are based on filenames of tables, not subjects or logical names;
- All tables should be in the same directory;
- The structure depicted in the table net window is not automatically updated when changes are made to the structure (tables should be saved first, and the net must be reopened);
- The Consultation environment and Intertabular verification only work with projects, not single tables.

Example:

Assume that 'ORDERS', 'CUSTOMER' and 'EXECUTE' are three tables in an Orders Problem.

The 'ORDERS' table contains a condition '^Customer', which will receive its value in the 'CUSTOMER' table. This table needs to have same filename as the condition and at least some of its action subjects should read Customer := Good, or some other value.
The 'ORDERS' table also contains an action '^EXECUTE', which refers to the filename of an action subtable.

2.3.1.3. Structure of a Prologa Project

A **Prologa** project is more than a simple collection of decision tables. From version 5.0 on, additional behavior has been stored in the project, making it easier to use and edit.
When a new condition or action is created in **Prologa**, the project component will automatically create a decision attribute or a subtable reference. These intelligent links are then maintained by the project with the following advantages:

- Faster navigation through the project, resulting in decreased execution times.
- Intelligent updates of all referenced conditions and actions.
- Intelligent value-editing (future versions).

Decision attributes

Many projects have recurring conditions, have actions that refer to other tables, or have actions that set the value of another table's condition. Sometimes the same condition occurs, but with different states.

It is clear, however, that these actions and conditions are related to a single piece of information, namely a decision attribute. **Prologa** maintains these decision attributes automatically and transparently. If a user enters, edits or deletes conditions or actions, the decision attributes are updated as well.

For example, when a new condition is added to a decision table, **Prologa** will look for an decision attribute that matches the condition name. If this decision attribute has been found, **Prologa** will automatically create a link to that decision attribute. If the decision attribute has not been found, a new one will be created.
The same goes for actions. Actions of the type 'Customer := Good' refer to the decision attribute named Customer.

Intelligent Linking

A project decision table now has some additional functionality compared to decision tables in earlier versions. This functionality reflects the inter-tabular relationships of the project, as well as the additional functionality stored with the conditions, condition states and actions.

For example, when entering the action '^SubTable', a reference to the table named '^SubTable' is automatically created. If there is no table with that name, a new table will be created automatically. If a table is deleted, but still has actions referring to it, these actions will be converted into simple actions, decision attributes will be created for these actions etc.

Advantages of decision attributes and intelligent linking in Prologa projects:

There are two main advantages to the use of decision attributes and intelligent linking.

First of all, if the name of a condition, action or table changes, and there are other references to the same decision attribute or table, the user has a choice to either:

- Cascade the change over the *entire project*. For example, if two conditions refer to the same decision attribute, and if the user changes the name of one of the conditions, the other condition's name will be updated automatically.
- Only change the *current object*. This will create a new decision attribute or table, and the changed object will be disconnected from the previous decision attribute or table.

The second advantage is faster navigation through the project. For example, when starting a consultation session, **Prologa** will automatically determine the main table of your project, using the information contained in conditions and actions.

2.3.2. Composition and Decomposition of Decision Tables

Prologa allows to move conditions or actions between tables, including the corresponding decision logic:

- Move conditions/actions including the decision logic from one table to another (using drag & drop);
- Join two tables into one (using drag & drop of the lower left part of a table into another);
- Decompose a table into separate tables, either independent or containing repetitions, using the Modularize option.

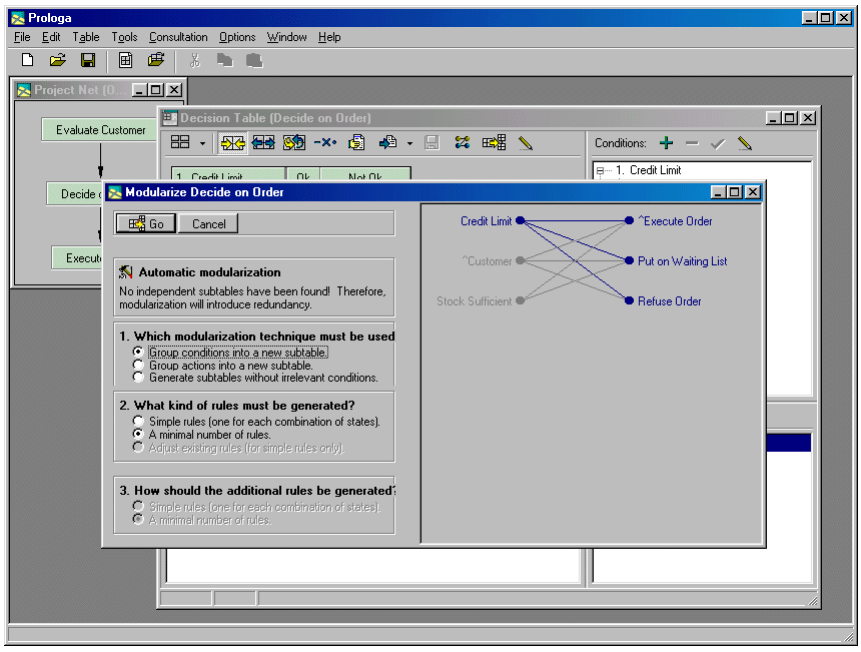

Prologa
File Edit Table Tools Consultation Options Window Help
Project Net (0...
Evaluate Customer
Decide
Execut
Decision Table (Decide on Order)
Conditions:
1. Credit Limit
Modularize Decide on Order
Go
Cancel
Automatic modularization
No independent subtables have been found! Therefore, modularization will introduce redundancy.
1. Which modularization technique must be used
Group conditions into a new subtable.
Group actions into a new subtable.
Generate subtables without irrelevant conditions.
2. What kind of rules must be generated?
Simple rules (one for each combination of states).
A minimal number of rules.
Adjust existing rules (for simple rules only).
3. How should the additional rules be generated?
Simple rules (one for each combination of states).
A minimal number of rules.
Credit Limit
^Customer
Stock Sufficient
^Execute Order
Put on Waiting List
Refuse Order

Figure 2-9. Modularization of a decision table

2.3.3. Intertabular V&V

Possible anomalies between tables in a project are examined in the intertabular V&V option (see the Tools Menu).

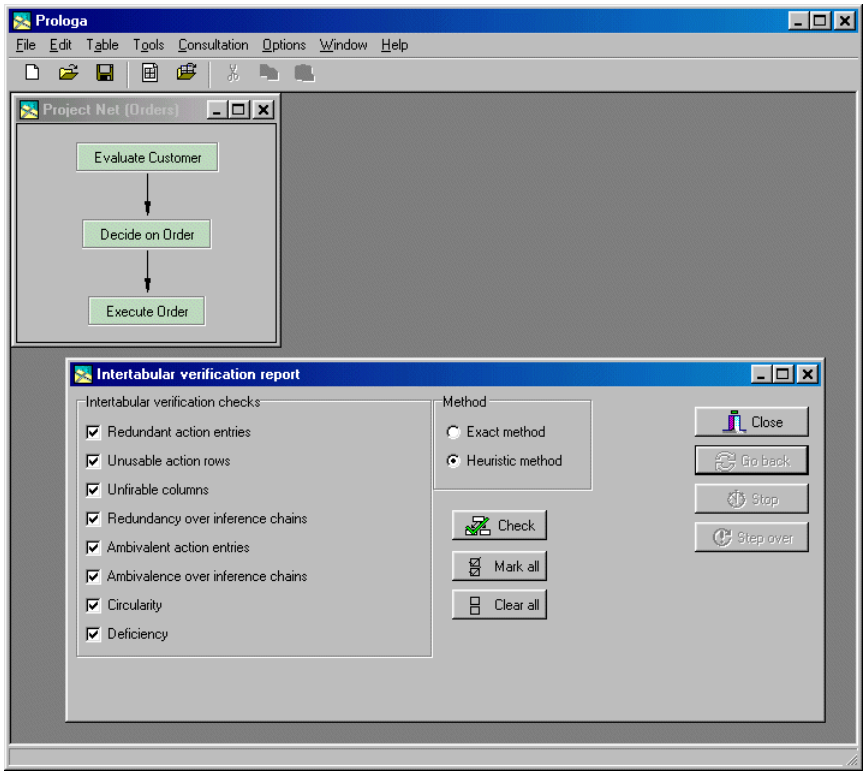


Figure 2-10. Intertabular V&V Report

2.3.4. Consultation of a Decision Table Project

Prologa enables the consultation of the decision tables in a project. During a consultation session, the system will inquire about the condition states of each relevant condition in the appropriate tables and, at the end, will present a list of actions to be taken.

The user is asked to select the appropriate condition states to find a unique column in the decision table (or all relevant decision tables). Only conditions relevant to the specific situation are presented, in the order in which they are included in the decision tables. As soon as such a unique column is discovered, the relevant actions are shown to the user.

It is also possible for a condition or action to call subtables. The process of switching from one table to another in a hierarchy of decision tables is performed entirely by the system and is transparent to the user. He does not (have to) know the exact structure of the application.

It goes without saying that this could easily be done manually for a single table, but in case the project contains several subtables, the advantages of the automated consultation system become clear. The subtables will be activated automatically, and when they are processed, the system will return to the place in the higher table from where the subtable was called. In this way a complete decision situation can be consulted via question and answer.

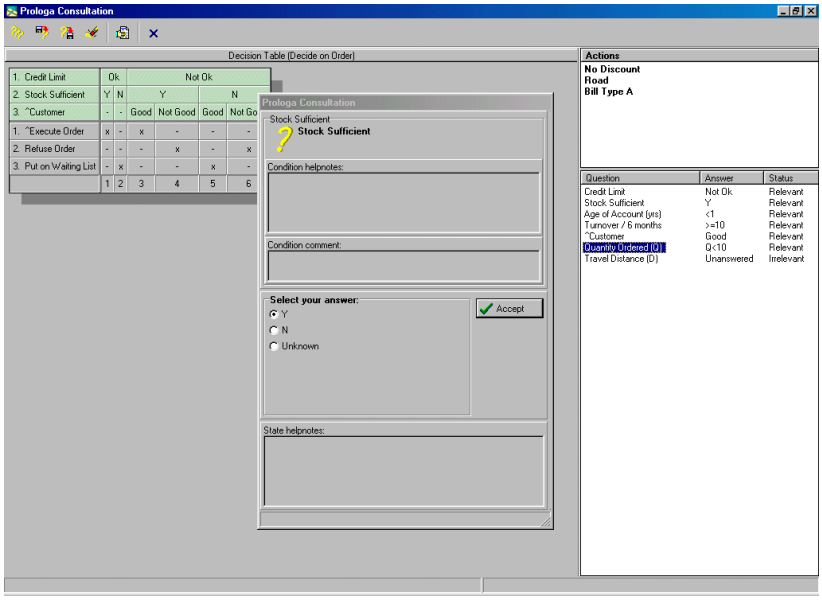


Figure 2-11. Consultation Environment

The decision table consultation environment also offers extensive consultation facilities which help the user to navigate through the application and find the right action(s): explanation, specific help, multimedia support, selective restart, case archivation, … .
For instance, there exists an option to change an answer that was previously entered (all other selections remaining equal) or to restart decision making. Together with the case archivation option this enables one to perform '**what-if**' analyses or to use standard cases.

2.3.5. Import from Excel

Prologa allows to import a decision table which is specified in an Excel spreadsheet (use the Tools menu). The spreadsheet contains a list of conditions with their states, a list of actions, a list of decision rules and a list of impossibilities. A wizard will guide the flexible import process. Take a look at the example spreadsheet on the distribution disk using the import wizard.

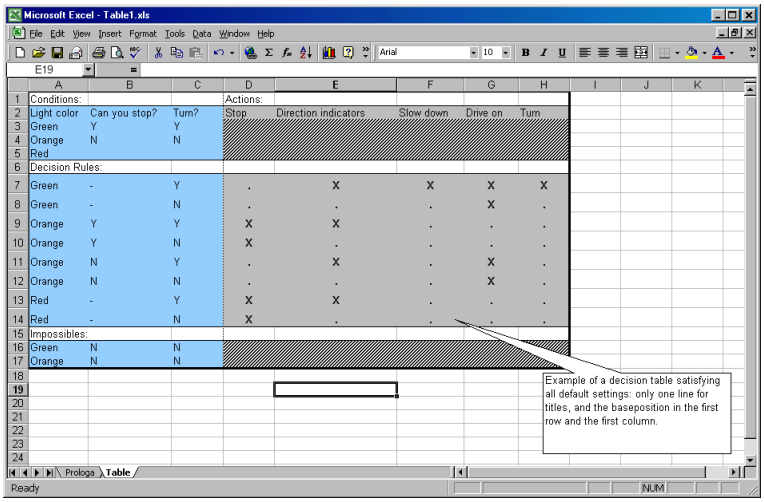

Microsoft Excel - Table1.xls
Example of a decision table satisfying all default settings: only one line for titles, and the baseposition in the first row and the first column.

Figure 2-12. Import from Excel

Figure 2-13. Selecting the Excel Workbook

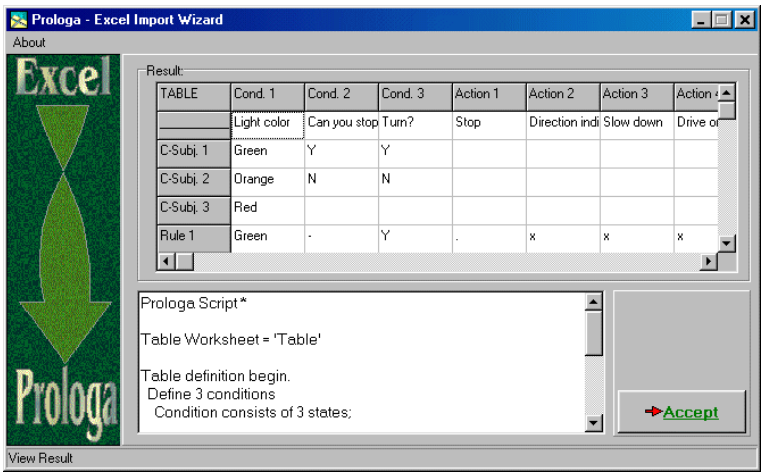


Figure 2-14. Importing using the Excel Wizard

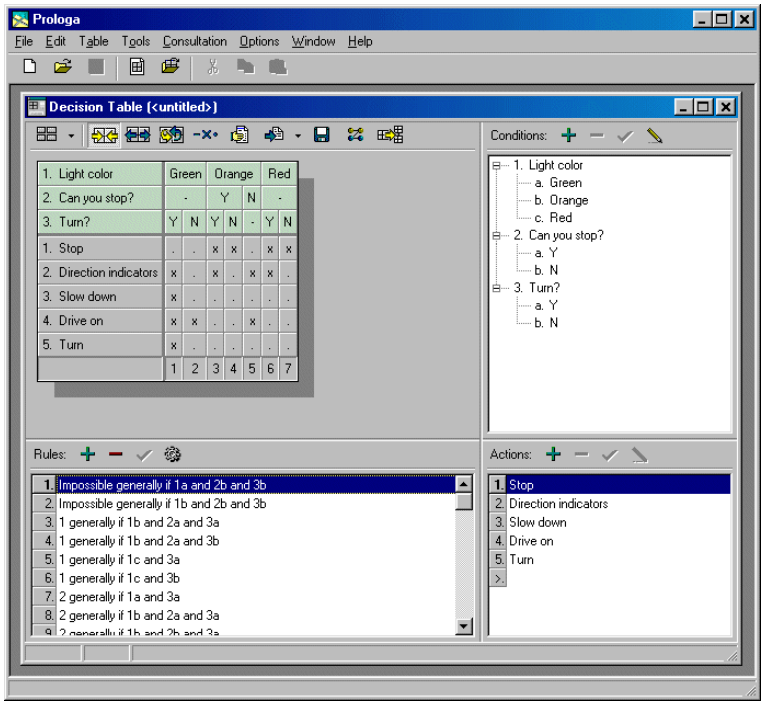


Figure 2-15. The Excel table imported into Prologa

2.4. Customizing Prologa

Prologa provides several default settings which can be customized by the user (e.g. colors, screen and table layout, directories, etc.). All these functions have been grouped under the Options pull-down menu.

Options can be customized to your own preferences and will then be **valid for all following sessions**. These preferences are stored in the PROLOGA.INI file.

If you have changed some settings and you want to return to the **Prologa** default settings, use the default button in the options menu.

2.4.1. Environment Settings

These settings allow you to change the directories where **Prologa** will look for projects or tables or where the various export-formats will be written.

Project Directory

The *Projects directory* is the default directory to store **Prologa** projects (default: Prologa\Projects). Projects will normally constitute a specific subdirectory.

Table Directory

The directory for single tables (no projects) is the *Table Directory* (default: Prologa\Tables).

Log Directory

Several Export possibilities are provided in **Prologa**. These commands will write to the Log Directory (default: Prologa\Log).
If you want your export files in the same directory as the original project, the log directory should be equal to the project directory.

2.4.2. Table Settings

Prologa allows you to customize the way a decision table is displayed. When selecting this command from the Options menu, a second menu level will appear on the screen.

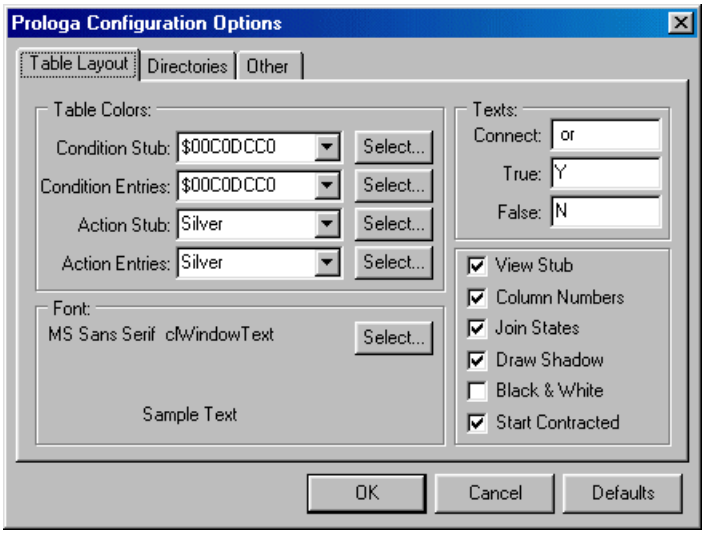


Figure 2-16. List of Table Options

Most of the options are self-explanatory (colors, fonts, visual elements).

Join States

With the 'join states' option, adjacent equal condition states for each condition are displayed only once (default). When unchecked, all states are repeated in every column.

Connect

Adjacent states leading to identical action configurations are then combined in one column and separated by this word or symbol.

E.g. if the separator is OR, two adjacent states `state 1` and `state 2`, leading to an identical result, will be combined in the table into `state 1 OR state 2`.

2.4.3. Table Net Settings

These settings allow you to modify the layout of the Project Net (showing the relations between tables in a project).

2.5. Advantages of Decision Table Automation

The construction of decision tables is a creative activity but it contains several routine operations which are quite time-consuming and error-prone. The use of a decision table tool does not only simplify the construction of the decision table, it also offers a number of extra advantages.

2.5.1. The Theory behind Decision Table Construction

Before considering computer support, we will first treat the *manual* ways to construct decision tables.
The choice of a suitable construction method will simplify the construction process and will increase both its efficiency and effectiveness. Depending on the characteristics of the problem domain, several methods can be distinguished. (VERHELST[80, chapter 2]):

1. the *direct method* : for well defined problems where specifications are relatively easy to find (specifications that are readily available, e.g. a text., are no guarantee that they are also easy to collect).

   a) based on *simple rules* : can be applied in all cases, is recommended once problems have a certain complexity.

   b) based on *combined rules* : for small or simple problems.

2. the *search method* : for problems not too well defined where it is difficult to obtain the specifications or where the specifications still have to be constructed.

These three methods follow comparable phases for analyzing the problem. The main difference between these methods is the order in which these phases are dealt with and the way they are worked out.

The following *phases* can be distinguished:

1. *Define the conditions, the condition states and the actions.*

The following steps have to be undertaken:

1.1. Draw up the list of all condition statements and actions that are mentioned in the specification.
1.2. Delete the restatements and the complements from this list.
1.3. Bring together the condition statements that are related to one condition subject such that an exhaustive set of mutual disjoint states is obtained for that condition.
1.4. Fill out the names of conditions and actions in the stub of the table. (Choose any natural order for the actions and conditions, taking into account possible order restrictions.)

2. *Define the rules*

During this phase, we describe the problem as a series of logical IF ... THEN ... relations where the connection is made between a combination of condition states and the actions that must be executed.

The following steps have to be dealt with:

2.1. Conceive the problem situation (without interpretation).
2.2. Determine the impossible condition combinations and the other relations between the conditions (or actions).
2.3. Describe the problem using logical expressions.

3. *Fill out the decision table.*

A distinction can be made between filling out the action part and the condition part of the table:

3.1. Fill out the condition entries of the table (the lower conditions will vary first).
3.2. Indicate all impossibilities. Depending on the preferred option, the impossibilities can be represented in the table in several ways.
3.3. Fill out the action entries (column by column or action by action).

4. *Check for completeness, correctness and consistency*

4.1. Examine the empty columns. These columns should to be examined one by one to verify if it really was the intention to have no actions.
4.2. Examine the unreferenced actions (or conditions).
4.3. Examine the completeness of actions and columns. Some actions or groups of actions should have at least one occurrence. This is usually the case if the actions are the representation of an "extended-entry" action (exhaustivity requirement).
4.4. Examine the table for contradictions. Some actions or action groups may exclude each other and therefore cause contradictions if they occur in the same column (exclusivity requirement).
4.5. Examine the table for correctness. Here we should not only check if the different columns correspond with the described specifications, but also if this specification corresponds with the desired reality.

5. *Simplify the decision table*

   5.1. Contraction of the table. Adjacent columns with the same action-configuration are contracted into combined columns. An optimal condition order might be computed to minimize the number of columns.
   5.2. Decide upon a suitable layout. To achieve this, several actions can be combined into extended entry actions, as long as this does not cause any contradictions.

6. *(Transform the decision table)*

   6.1. Depending upon its purpose, the decision table might be converted into a consultation system, a program with minimal execution time, etc.

2.5.2. Why use a decision table tool?

The use of a computer does not only simplify the construction of the decision table, it also offers a number of extra advantages.

We enumerate the advantages ordered by increasing involvement of computer use:

. The *writing and drawing* that has to be performed when constructing decision tables, can be taken over completely by the computer.

. A number of *routine jobs* that induce many errors while filling out (or especially when changing) the table, can be completed faster and more correct by the computer, for instance: adding action entries, generating the condition combinations (without any missing combinations).

. Some *manipulations of the decision table* which are difficult to perform manually, such as the reordering of conditions and actions, can easily be performed now.

. Introducing a workbench in the design process provides *interactive possibilities* that simplify the design process, such as automatic checking for consistency, correctness and completeness or recommendations for a specific construction method.

. The system can be used for *optimization* purposes, such as optimal contraction, layout, decomposition into subtables or conversion into efficient program code.

2.6. Prologa and Validation of Knowledge

It is important that knowledge in decision situations is correct, consistent, complete and non-redundant. During and after the building process, the knowledge base must be verified and validated, which proves to be one of the main problem areas in designing intelligent systems.

Knowledge validation occurs at several instances during the building process:

- A first validation takes place during the *knowledge elicitation* stage. When acquiring knowledge, the knowledge engineer will look for incomplete specifications, ambiguities, redundancies in order to direct and improve the elicitation process.

- In the *knowledge modeling* stage, the development interface of the system building tool will (or should) verify the knowledge structuring effort (not only syntactical elements, but also semantics). Very often, graphical representations of links between knowledge elements are used in this stage.

- When the application has been designed, the knowledge base has to be *tested* (using prototyping facilities, debugging, test data management, reasoning trees, tracing and logging).

- The validation process resumes while *maintaining* the knowledge base.

In a vast majority of cases, the decision table technique is able to provide for extensive validation and verification assistance(MERLEVEDE & VANTHIENEN [91]). It easily enables the designer to check for contradictions, inconsistencies, incompleteness, redundancy, etc. in the problem specification. Moreover, the knowledge acquisition process is well served through the overview and communication abilities of well-structured decision tables.

Prologa easily solves (or avoids) these common validation problems in rule based systems, e.g. redundant rules, conflicting rules, subsumed rules, unnecessary conditions, circular rules, missing rules or combinations, unreferenced attribute values, illegal attribute values, dead end clauses.

2.6.1. Consistency and Correctness of Knowledge

Dividing the knowledge over a large number of rules, designed independently, may lead to problems of consistency (LOVELAND & VALTORTA[1], BRAMER[2]), such as:

- **Conflict**: rules with the same premises (or containing overlapping combinations), but leading to contradictory conclusions.
  In a decision table all columns are non-overlapping and each column refers to exactly one configuration of conclusions, therefore conflict will not occur. During the building process, **Prologa** allows the designer to override previous configurations or will indicate contradictions in the table;

- **Cyclical rules**: a set of rules where a conclusion occurs somewhere as one of the premises.
  In a decision table context, conclusions occurring as premises lead to separate tables. The forward character of the decision table structure, though less flexible in general, eliminates the problem of cyclical references;

- **Invalid attribute values**: a rule containing a nonexistent value of an attribute (e.g. because of a typing error).
  By defining the domain of conditions and performing type checking, invalid values are easily detected;

- **Unreachable conditions**: conditions which cannot be asked or concluded from other rules are easily discovered in a set of decision tables.

---

1. LOVELAND, D., VALTORTA, M. [83], *Detecting Ambiguity : An Example in Knowledge Evaluation*, Proc. Eighth Intl Joint Conf. on Artificial Intelligence, Karlsruhe, Aug. 1983, Vol. 1, pp. 182-184.

2. BRAMER, M. (Ed.), *Research & Development in Expert Systems*, Proc. Fourth Technical Conf. on Expert Systems, Cambridge University Press, 1985, 228 pp., pp. 185-192.

2.6.2. Non-redundancy of Knowledge

Redundancy usually does not lead to errors during consultation of the system, but may harm efficiency. The main problem with redundancy, however, is not inefficiency, but maintenance and the risk of creating inconsistencies when changing the knowledge base. Moreover, the uncertainty calculations might be affected by redundant knowledge. Some common forms of redundancy:

- **Subsumption**: rules with the same conclusions but with one of them containing additional premises (and therefore being less general).
  Subsumption will not occur in the decision table, because columns do not overlap;

- **Redundant premises**: (partly) complementary rules with equal conclusions, which can be combined.
  In a compressed decision table, two or more complementary rules with equal action configurations are automatically combined, leading to irrelevant or partly irrelevant conditions. The number of distinct columns is thereby minimized. **Prologa** will also indicate conditions which are never referenced;

- **Redundant rules**: rules with the same premises and (partly) equal conclusions.
  Because in the decision table every possible case is included in only one column (exclusivity), redundancies will not occur.

2.6.3. Completeness of Knowledge

No current system is able to incorporate all possible knowledge, but within the specific problem area, the following omissions often occur:

- **Missing knowledge**: the absence of some essential elements from the problem situation. Inconsistency e.g. might indicate missing premises;

- **Unused attribute values or combinations**: when possible attribute values (or combinations) never occur as premises, a number of rules is missing. Detecting the completeness of all combinations of attribute values is not always simple.
  The nature of the decision table easily allows to check for completeness: the number of simple columns should equal the product of the number of states for every condition. This guaranty of completeness of condition combinations is one of the main advantages of decision tables. **Prologa** will automatically generate all combinations and indicate attribute combinations where no conclusions are provided;

- **Unreachable conclusions**: conclusions which are never deduced and cannot be asked.
  The format of the decision table easily shows unreachable conclusions. **Prologa** will indicate conclusions which are never referenced.

Detecting these shortcomings (either by the designer or automatically), without some form of decision tables, is highly improbable, unless through excessive testing, which is already a problem due to the current lack of automatic testing facilities.

3. Prologa Step By Step

Other chapters explain the theory behind **Prologa**, as well as the **Prologa** tool. The best way to understand these chapters fully is by using the tool. This chapter describes four applications of decision tables, each one is modeled using **Prologa**. The first two examples are completely worked out and explain step by step how the problem can be solved. The third problem is discussed from a theoretical point of view. The fourth problem if left as an exercise to the reader. The solutions to the problems can be found on the distribution disk.

For the first two examples, the direct method for constructing a decision table will be used starting from a text. We will guide you through a complete session, from knowledge acquisition to the implementation of the resulting decision table(s). It is however not the purpose to explain all **Prologa** screens again. We strongly recommend to make this exercise using the computer.

3.1. Holidays, A simple one-table example

The first application is a simple knowledge based system that will be used by the Personnel Department of a small company. We will assume that the resulting code has to be embedded in a program.
The first step in the development process is knowledge acquisition. If information is available in written form, this knowledge can easily be structured using the direct method for constructing decision tables. This is often the case for existing regulations in a business environment.
The text found in the rule book of the company is depicted in the following figure.

HOLIDAYS

The number of holidays depends on age and years of service.

Every employee receives at least 22 days.
Additional days are provided according to the following criteria:

Young employees (less than 18) receive 5 extra days.

If an employee has at least 25 years of service, 2 extra days are given. These 2 days are also provided for employees of age 45 or more, irrespective of their years of service.

Employees with at least 40 years of service and also employees of age 60 or more, receive 3 extra days, on top of the additional days already given.

Figure 3-1. The regulations for holidays, as found in a rule book

The phases for analyzing the problem have been described elsewhere. We will go through these phases step by step and build the decision table using **Prologa**.

3.1.1. Start new table

Start **Prologa**, and select New from the File menu. When saving, enter Holidays as table name.

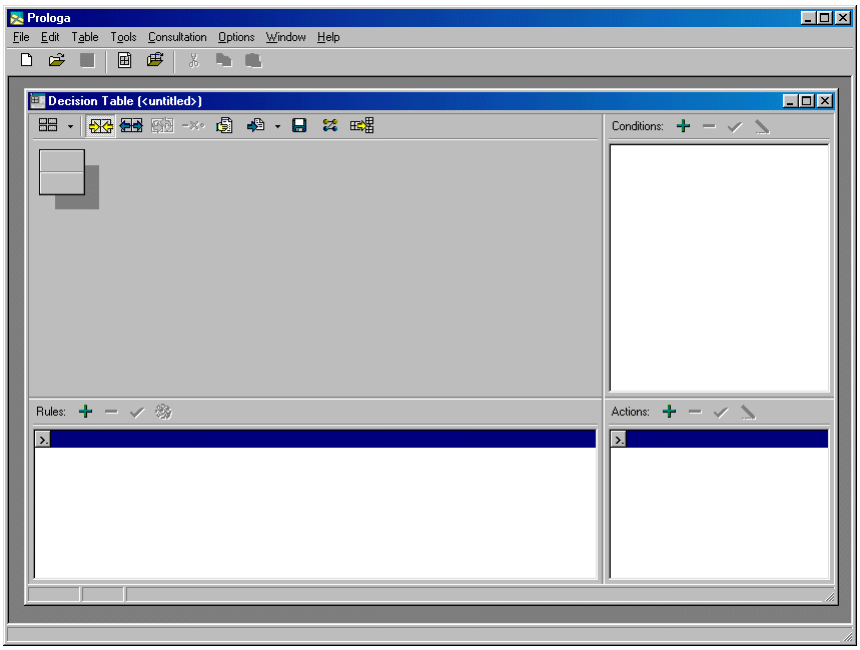


Figure 3-2. Starting a new table

3.1.2. Define the Conditions, Condition States and Actions

First we draw up the list of all condition statements and actions that are mentioned in the text. The result can be seen in the following table.

Condition Statements	**Action Statements**
Age	Number of Holidays
Years of Service	At least 22 days
Every Employee	Additional days
Less than 18	5 extra days
>= 25 years of service	2 extra days
Age >= 45 years	2 extra days
irrespective of years of service	3 extra days on top
>= 40 years of service	
Age >= 60 years	

Table 3-1. Exhaustive List of Condition Statements and Actions in text

Now we delete the restatements and the complements of the list:

Condition Statements	Actions
Less than 18	Assign 22 days
>= 25 years of service	5 extra days
Age >= 45 years	2 extra days
>= 40 years of service	3 extra days
Age >= 60 years	

Table 3-2. Reordered List of Condition Statements and Actions

The list of condition statements has to be checked for completeness. Each condition should have an exhaustive set of mutual disjoint states. This is done by putting the different states of a condition on a scale, as can be seen in Figure 3-3.

Age	years < 18 | 18<= years < 45 | 45 <= years < 60 | years >= 60
Service	years < 25 | 25 <= years < 40 | years >= 40

Figure 3-3. Condition Scales for the Holiday Regulations

Based on these enumerations, we can now fill out the conditions, condition states and actions of our decision table. This is done using the '+' sign in the condition editor and action editor in **Prologa**. Now the conditions can be entered together with their states. Enter the information from Figure 3-3 into the Condition editor. Once this is done, also enter the actions from the actions column. Your screen should then look similar to the screen depicted in Figure 3-4.

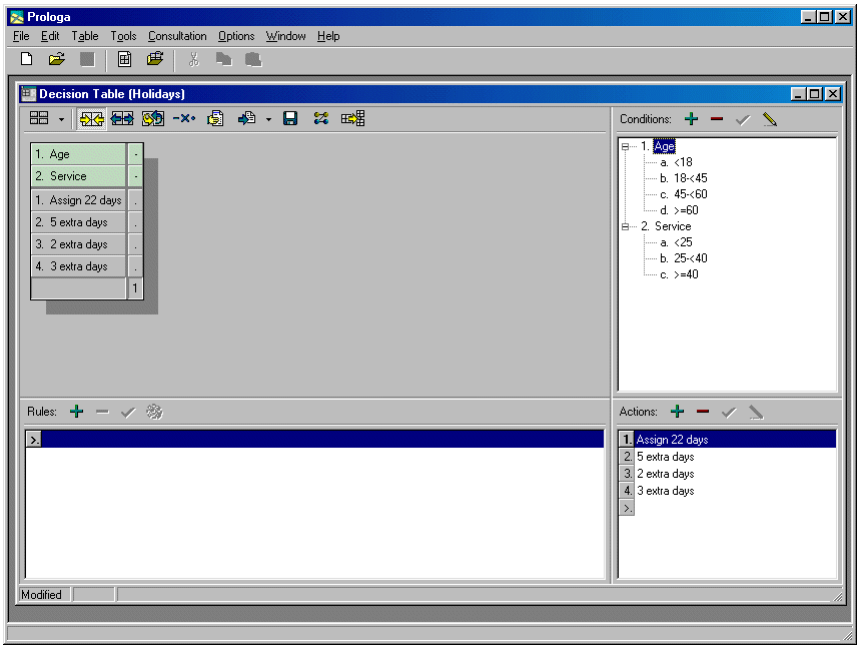


Figure 3-4. Prologa's Condition and Action Editor

3.1.3. Define the Decision Rules

Based on the text of the regulations and on the conditions, the condition states and the actions, we can now proceed by filling out the rules in the **Prologa** Rule Editor. We simply read each line in

the regulations and translate it into a **Prologa** rule. These rules can be entered immediately into the rule editor.

Every employee receives at least 22 days
Action 1 always has to be performed: there are no conditions. Just entering the action will do.
Type: `1`
As you will see, **Prologa** will translate the entry into a more readable form. In this case this will give the following result:
Result: `1 definitely if always`

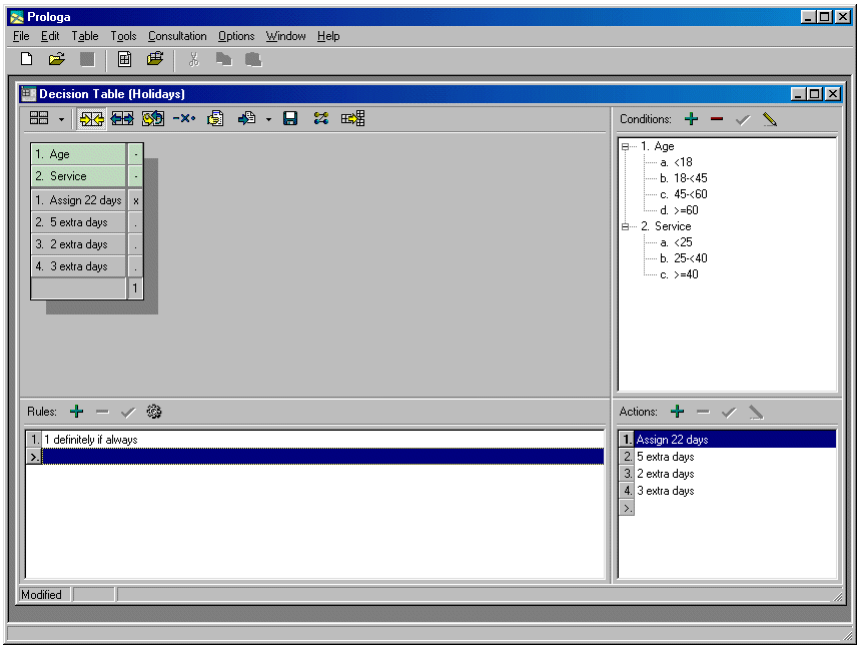


Figure 3-5. Entering a decision rule

Young employees (less than 18) receive 5 extra days
Action 2 (5 extra days) has to be performed if Age<18. This condition corresponds to state 1a. Since we always enter the action first, the resulting rule is entered as follows:
Type: `2 if 1a`
Result: `2 generally if 1a`

For the two following rules we just give the result. The reasoning behind it is left as an exercise.
If an employee has at least 25 years of service, 2 extra days are given. These 2 days are also provided for employees of age 45 or more, irrespective of their years of service.
Result: `3 generally if (2b or 2c) or (1c or 1d)`

Employees with at least 40 years of service and also employees of age 60 or more, receive 3 extra days, on top of the additional days already given.
Result: `4 generally if 2c or 1d`

Notes
- States of one condition can only be connected by OR. Therefore (2b or 2c) can be abbreviated to 2bc.
- The rules 3 and 4 can also be split up in several rules. There is no obligation at all to have only one rule per action. For instance, we could replace the third rule by the following two rules:

```
3 generally if (2b or 2c)
3 generally if (1c or 1d)
```

3.1.4. The constructed Decision Table

While conditions, actions or rules are entered, the decision table view is always up to date. This is performed automatically by **Prologa**. After entering the decision rules, the table looks as depicted in Figure 3-6.

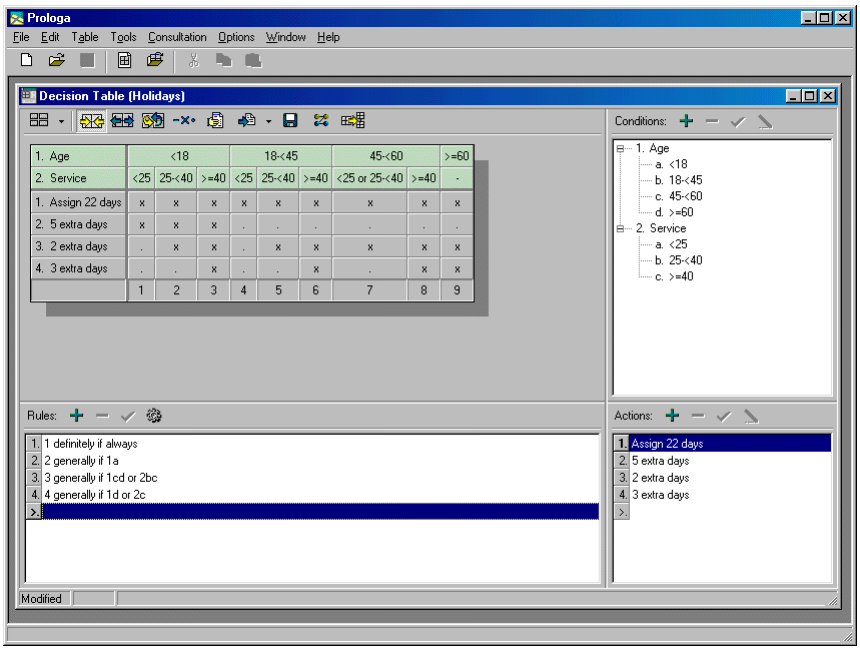


Figure 3-6. A first View of the Decision Table

3.1.5. Verify Completeness and Consistency

Empty columns, unreferenced actions or unreferenced conditions do not occur in this example.

When, however, we take a good look at the preliminary decision table, we see that it should be impossible for an employee younger than 18 years to have 25 or more years of service. Indeed, this case was not excluded by the rules. Of course, we would probably prefer to discard this impossible situation. This can be done by adding a new rule, stating that an employee younger than 18 definitely cannot be more than 25 or more than 40 years in service. Since children are not allowed to work, we can also add a rule that employees younger than 45 can not have 40 years of service in the company.

Result:
```
impossible definitely if 1a and (2b or 2c)
impossible definitely if 1b and 2c
```

Note

We strongly recommend the use of impossibilities.

- In fact, one should look for semantic impossibilities before entering the rules. Deletion of impossible situations will ease the verification process.
- By definition, semantic impossibilities should be used in combination with "definitely if". If "generally if" would be used, other rules could overrule this impossibility.

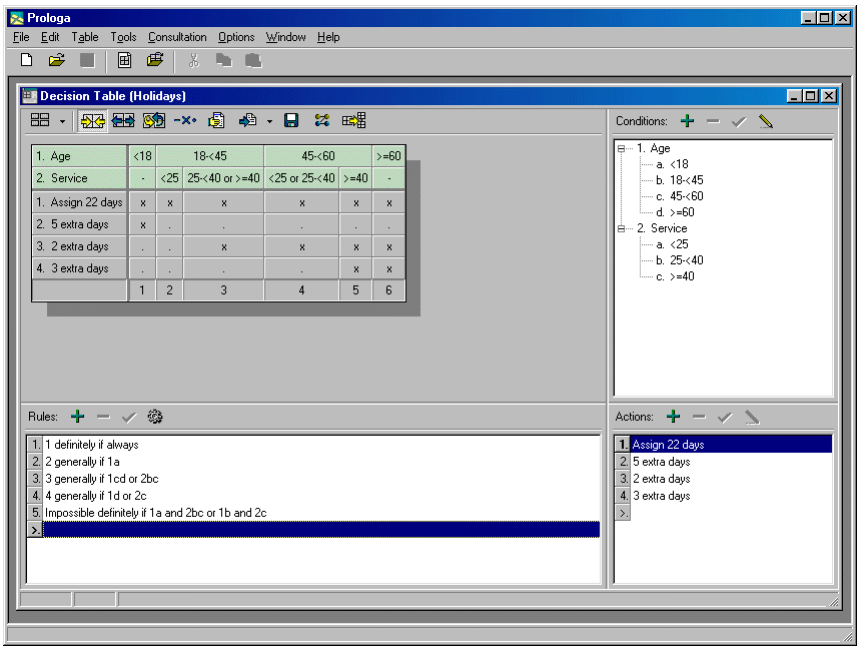


Figure 3-7. The final Decision Table

3.1.6. Validate Correctness

This last check is a double one. First we verify if the different columns of the decision table correspond with the described specifications. For this example this is the case. If this is not the case, it means that the interpretation of the text is wrong, or in other words one of the rules does not correspond to the text.
Second, one has to check if the decision table corresponds to the desired reality. For instance, it could be possible that management would prefer to give an extra day after 10 years in service, even if this is not mentioned in the text. This is exactly what has to be checked: (1) does the text fully represent the current situation?, and (2) does it represent the desired situation?

3.1.7. Simplify the Decision Table

Once a complete validation of the decision table is finished, the table should be reduced to its minimal format. We strongly recommend the use of the expanded table for knowledge verification! This form gives a better overview, especially to compare the decision table with the desired reality. To view the expanded table, press the "expand" button in the table menu.

3.1.7.1. Contraction of the decision table

As mentioned above, this is done automatically in **Prologa** when the table option "Start Contracted" is checked (default).

3.1.7.2. Decide upon the suitable layout

The order of the conditions might influence the number of columns in the contracted table. The optimal order can be obtained using **Prologa**. Select the Optimize Table button from the table menu. For this example, the original condition order is already the optimal one.

3.2. An Order Processing Problem

This example is a typical example of the application of decision tables (VERHELST [80]). We have chosen this problem because it is well suited to construct a system of tables, and because some 'mistakes' are built in. It shows why decision tables are better for regulations than e.g. written texts. In this example we start from the text used to take decisions for order processing. During the decision table validation several 'mistakes' will be discovered.

3.2.1. The text of the order processing policy

Figure 3-8 gives the complete text of the order processing policy as it is applied currently. As we will see, this text contains some 'mistakes'.

Order Processing

First we check whether the credit limit has not been exceeded. If this is not the case, the stock will be checked. If the product is in stock, the order will be executed, else we put the order on the waiting list. If the credit limit has been exceeded, the same measures will apply if the customer is important. If this is not the case, the order will be rejected

Whether a customer is important depends primarily on the age of the account. If the customer did register less than a year ago, the turnover over the last 6 months has to be at least $10,000 to qualify as an important customer. For all other clients, the critical turnover point has been set to $5,000$.

Three critical points have to be taken into account while executing the order :

1. Discount
The discount rates are 10%, 5% and 2% : 10% for clients with an order quantity of at least 15 pieces or who are situated within a range of less than 50 miles of the company and order at least 10 pieces; a discount of 5% is allowed to those customers that order at least 10, but less than 15 pieces and whose distance to the company is more than 50 miles; finally, the discount rate comes to 2% for customers that live at least 100 miles from the company, and order at least 10 but less than 15 pieces.

2. Means of Transport
We deliver by rail if the order comes from a customer that has ordered at least 15 pieces. In all other cases, road transport is used.

3. Bill Type
The normal bill type is A. Exceptionally, a type B bill has to be made up. This is the case when a customer's order quantity is at least 15 pieces.

Figure 3-8. The Order Processing Policy

With this text, we can start the construction method of decision tables. As in the previous example, all steps will be discussed in detail.

3.2.2. Defining subproblems

After careful reading of the text, one can see that it is quite difficult to represent the problem by one table. Indeed, already in the first paragraph enough indications show that some subtables have to be used. First, there is the decision whether a customer is important or not. This decision is discussed in the second paragraph. We prefer to put this decision in a condition subtable. Second, the action 'execute order' is worked out in the third part of the text. We prefer to see this action as an action subtable.
From these considerations we deduce the following intuitive rule : *When a problem can be split up in clearly defined subproblems, the decision table should have subtables*.
Since the order processing policy is now split out over three tables, we have a table structure. For real problems, we will often have even more tables.
The particular table structure, which will be reached at the end of this example, is shown in Figure 3-9.

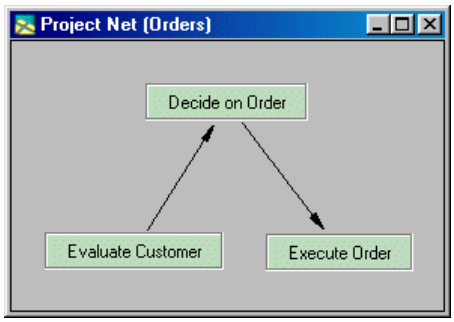


Figure 3-9. The table structure for the ORDERS problem

3.2.3. Starting a new Project

In order to input the first table, we start a new project (‘Orders’) and choose a name for the first table, as indicated in Figure 3-10.

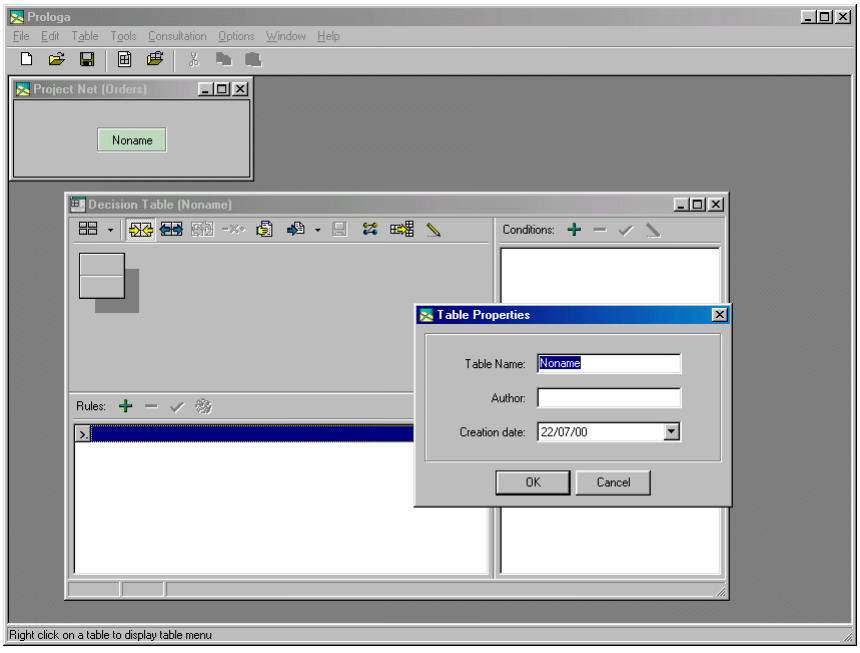


Figure 3-10. Starting a new project

3.2.4. Define the Conditions, Condition States and the Actions

Since the procedure for deriving conditions, condition states and actions is exactly the same as for the Holidays example, we only give the final results (after regrouping, restatement and deletion of complements). Table 3-3 represents the first paragraph, which will result in the 'Decide on Order' table, Table 3-4 represents the second paragraph, which will result in the 'Evaluate Customer' table and finally Table 3-5 will result in the 'Execute Order' table.

Condition Statements	**Action Statements**
Credit Limit OK	Execute Order
Customer Good	Refuse Order
Stock Sufficient	Put On Waiting List

Table 3-3. Conditions and actions for 'Decide on Order'

Condition Statements	**Action Statements**
Age of Account < 1 year	Customer := Not Good
Turnover / 6 months >= $10,000	Customer := Good
Turnover / 6 months >= $5,000	

Table 3-4. Conditions and actions for 'Evaluate Customer'

Condition Statements	**Action Statements**
Quantity ordered >= 15	Discount Rate 10%
Quantity ordered >= 10	Discount Rate 5%
Distance < 50 miles	Discount Rate 2%
Distance < 100 miles	Railway Transport
	Road Transport
	Bill Type A
	Bill Type B

Table 3-5. Conditions and actions for 'Execute Order'

Decide on Order

Credit Limit	OK | Not OK
Customer	Good | Not Good
Stock Sufficient	Yes | No

Evaluate Customer

Age of Account	< 1 year | >= 1 year
Turnover / 6 months	< 5,000 | 5,000 - < 10,000 | >= 10,000

Execute Order

Quantity Ordered	< 10 | 10 - < 15 | >= 15
Distance (Miles)	< 50 | 50 - < 100 | >= 100

Figure 3-11. Condition Scales for the order processing problem

Based on these enumerations, we can fill out the conditions, condition states and actions for the three tables. By entering '^Customer' as the condition name, and '^Execute Order' as the action name in the main table, the two subtables are created.

3.2.5. Define the Rules

Based on the text of the policy we now define the rules for the three decision tables. Rules are entered in the **Prologa** Rule Editor.

3.2.5.1. The rules for 'Decide on Order'

The first paragraph of the text already shows that this problem is formulated in a more complex way than the Holidays example we treated in the first part of this chapter. Here we really have to read the text carefully line by line to understand what is really meant.

First we check whether the credit limit has not been exceeded. If this is not the case, the stock will be checked. If the product is in stock, the order will be executed, else we put the order on the waiting list.
If the credit limit has been exceeded, the same measures will apply if the customer is important. If this is not the case, the order will be rejected

It is not possible to translate each line of this regulation in one decision rule, as we did in the Holidays example. This approach can only be followed if the lines or sentences are really independent of each other. Therefore we turn to the actions. For each action a separate rule is deduced from the text :

Execute Order if (Credit Limit OK or (Credit Limit not OK and Customer Good))
and Stock Sufficient

```
1 generally if only 1a or (1b and 2a) and 3a
```

Refuse Order if Credit Limit not OK and Customer not Good

```
2 generally if only 1b and 2b
```

Put On Waiting List if (Credit Limit OK or (Credit Limit not OK and Customer Good))
and Stock not Sufficient

```
3 generally if only 1a or (1b and 2a) and 3b
```

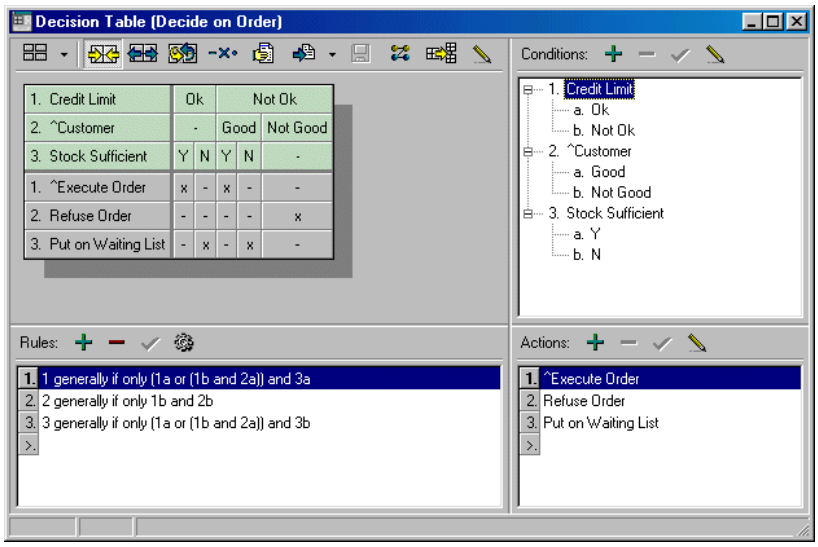


Figure 3-12. The table 'Decide on Order'

Note: The 'if only' (= if and only if) operator indicates that the specific action is only applicable in the cases mentioned. In all other cases the action will not be executed. Therefore a '-' symbol is introduced in the decision table for all other columns of the action row.

3.2.5.2. The rules for 'Evaluate Customer'

If the customer did register less than a year ago, the turnover over the last 6 months has to be at least $10,000 to qualify as an important customer. For all other clients, the critical turnover point has been set to $5,000$.

```
Only 2 generally if 1a and 2c or 1b and 2bc                    (1)
```

In all other cases, the customer is not good.

```
Only 1 generally if not rule 1                                 (2)
```

This second rule illustrates the power of **Prologa**'s decision rule syntax. One can refer to another rule for the conditions of a new rule. Here we negate the conditions of rule 1.

Note: It is possible to write something like `NOT (Rule 1 OR Rule 2 OR Rule 3)`. However, this might lead to a combinatorial explosion. We recommend the use of the Rule-statement for the negation of one earlier rule only.

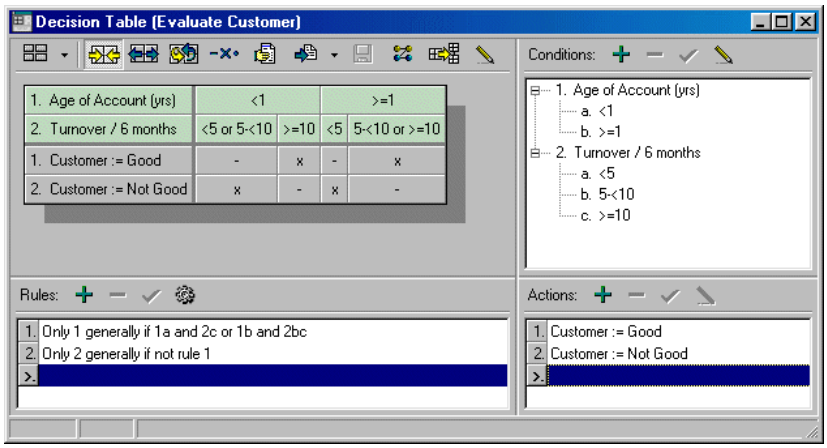


Figure 3-13. The table 'Evaluate Customer'

3.2.5.3. The rules for 'Execute Order'

1. Discount
The first of the three paragraphs deals with the discount that will be given. This paragraph can be cut into 3 parts, one for each reduction rate:

10% for clients with an order quantity of at least 15 pieces or who are situated within a range of less than 50 miles of the company and order at least 10 pieces;

```
1 generally if only 1c or 1bc and 2a                           (1)
```

a discount of 5% is allowed to those customers that order at least 10, but less than 15 pieces and whose distance to the company is more than 50 miles;

```
2 generally if only 1b and 2bc                                 (2)
```

finally, the discount rate comes to 2% for customers that live at least 100 miles from the company, and order at least 10 but less than 15 pieces.

```
3 generally if only 2c and 1b                                  (3)
```

We suppose that all other situations lead to a discount of 0%. Although this action was not specifically mentioned in the text, we already add it, as it will come up as a result of the verification process later.

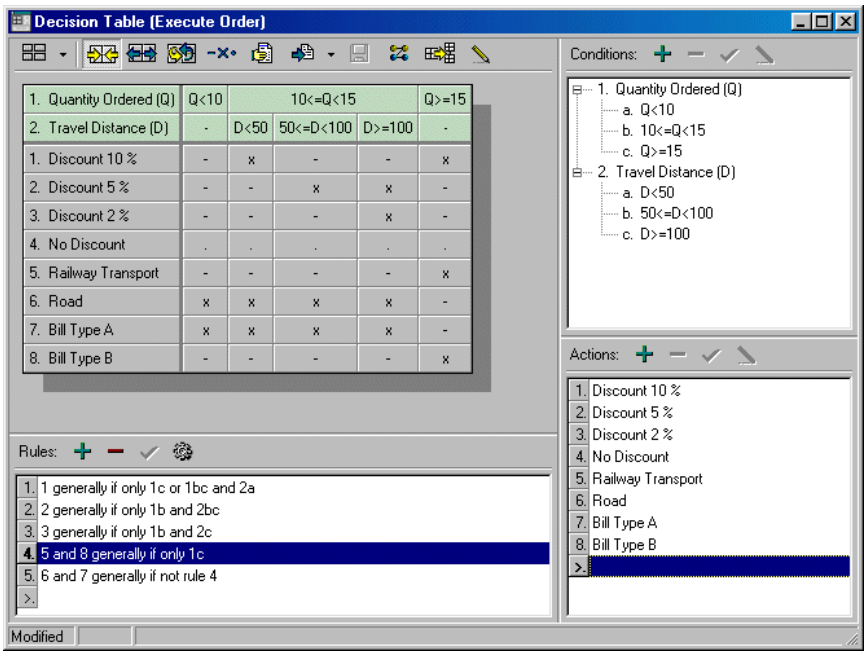
We consider Means of Transport and Bill Type together:

2. Means of Transport
We deliver by rail if the order comes from a customer that has ordered at least 15 pieces. In all other cases, road transport is used.

3. Bill Type
The normal bill type is A. Exceptionally, a type B bill has to be made up. This is the case when a customer's order quantity is at least 15 pieces.

These 2 paragraphs result in the following rules:

```
5 and 8 generally if only 1c                    (4)
6 and 7 generally if not rule 4                 (5)
```


Decision Table (Execute Order)
Conditions:
1. Quantity Ordered (Q)
a. Q<10
b. 10<=Q<15
c. Q>=15
2. Travel Distance (D)
a. D<50
b. 50<=D<100
c. D>=100
Actions:
1. Discount 10 %
2. Discount 5 %
3. Discount 2 %
4. No Discount
5. Railway Transport
6. Road
7. Bill Type A
8. Bill Type B
Rules:
1. 1 generally if only 1c or 1bc and 2a
2. 2 generally if only 1b and 2bc
3. 3 generally if only 1b and 2c
4. 5 and 8 generally if only 1c
5. 6 and 7 generally if not rule 4
Modified

1. Quantity Ordered (Q)	Q<10	10<=Q<15			Q>=15
2. Travel Distance (D)	-	D<50	50<=D<100	D>=100	-
1. Discount 10 %	-	x	-	-	x
2. Discount 5 %	-	-	x	x	-
3. Discount 2 %	-	-	-	x	-
4. No Discount	.	.	.	.	.
5. Railway Transport	-	-	-	-	x
6. Road	x	x	x	x	-
7. Bill Type A	x	x	x	x	-
8. Bill Type B	-	-	-	-	x

Figure 3-14. The preliminary table 'Execute Order'

3.2.6. Fill out the Decision Tables

As already explained, this step is performed automatically by **Prologa**. If the table contraction option is checked, the tables will look as shown above.

3.2.7. Check for Completeness, Correctness and Consistency

For the 'Decide on Order' and for the 'Evaluate Customer' decision tables there are no real verification problems. We leave these two tables as an exercise and turn immediately to the third table 'Execute Order'.

3.2.7.1. Examine the empty columns

No empty columns are present in the decision table.

3.2.7.2. Examine the unreferenced actions and conditions

When we look at the 'Execute Order' table with the current set of rules, we can see that action 4 ('No discount') is still unreferenced. This is normal because we did not define a rule for this action.

3.2.7.3. Examine the completeness of actions and columns

Column 1 of the table does not contain a discount value. Probably we want action 4 ('No discount) for this column. However, this is not mentioned in the text and therefore was not included in the rules.

3.2.7.4. Examine the table for contradictions

There is a contradiction in column 4. When the quantity is between 10 and 15 pieces and the distance is more than 100 miles, the customer would get 2 discounts (5% and 2%). Since we presume that the discount rates exclude each other, this has to be wrong. At least one of the decision rules leading to this conclusion will have to be changed.

3.2.7.5. Examine the table for correctness

The decision table fully represents the text of the order processing policy. However, this policy contains contradictions and is not really complete. Using the text can result in different reductions depending on how it is read. The company has to adapt its policy to make it consistent.

We can assume that the following text was really meant:

The discount rates are 10%, 5%, 2% and 0% :

- *10% for clients with an order quantity of at least 15 pieces or who are situated within a range of less than 50 miles of the company and order at least 10 pieces;*
- *a discount of 5% is allowed to those customers that order at least 10, but less than 15 pieces and whose distance to the company is more than 50 miles* ***but less than 100 miles****;*
- *the discount rate comes to 2% for customers that live at least 100 miles from the company, and order at least 10 but less than 15 pieces.*
- ***If none of the previous cases can be applied, no discount (discount rate = 0%) has to be given****.*

This text is corresponds to the 'Orders' decision table project as it can be found on the distribution disk.

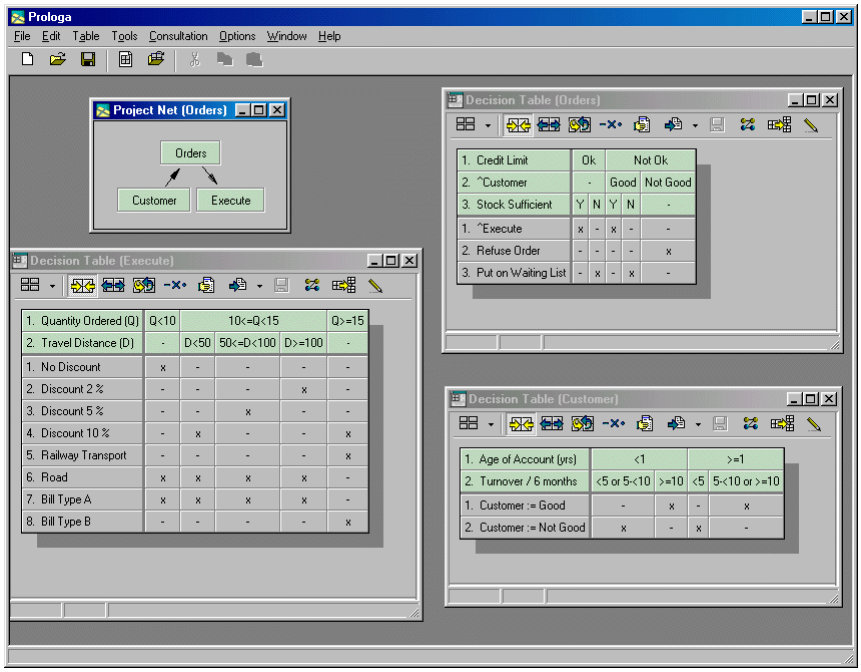

Prologa
File Edit Table Tools Consultation Options Window Help
Project Net (Orders)
Orders
Customer
Execute
Decision Table (Orders)
1. Credit Limit | Ok | Not Ok
2. ^Customer | - | Good | Not Good
3. Stock Sufficient | Y | N | Y | N | -
1. ^Execute | x | - | x | - | -
2. Refuse Order | - | - | - | - | x
3. Put on Waiting List | - | x | - | x | -
Decision Table (Execute)
1. Quantity Ordered (Q) | Q<10 | 10<=Q<15 | Q>=15
2. Travel Distance (D) | - | D<50 | 50<=D<100 | D>=100 | -
1. No Discount | x | - | - | - | -
2. Discount 2 % | - | - | - | x | -
3. Discount 5 % | - | - | x | - | -
4. Discount 10 % | - | x | - | - | x
5. Railway Transport | - | - | - | - | x
6. Road | x | x | x | x | -
7. Bill Type A | x | x | x | x | -
8. Bill Type B | - | - | - | - | x
Decision Table (Customer)
1. Age of Account (yrs) | <1 | >=1
2. Turnover / 6 months | <5 or 5-<10 | >=10 | <5 | 5-<10 or >=10
1. Customer := Good | - | x | - | x
2. Customer := Not Good | x | - | x | -

Figure 3-15. The final tables for the order processing example

3.2.8. Simplify the decision tables

As described earlier, two simplifications can be made:

- contracting the table with the same condition order (was done automatically by **Prologa**);
- applying optimal contraction, looking for the condition order that results in the smallest table. No improvements to be made in this example.

3.3. Different ways to solve a classification Problem

An example is given of a small deterministic expert system for animal classification. The purpose of this system is to determine the (sub)category and, possibly, the name of a specific animal, from a number of observed attributes. This example illustrates how the decision table approach not only preserves the advantages of rule based systems (through the formulation of decision rules), but also offers (i) a better overview, (ii) ease of checking for completeness and consistency, and (iii) a more efficient execution.

This example has not been worked out completely, as was the case for the two previous exercises. However, since the solution is illustrated quite well, it shouldn't be a problem to try it out yourself.

The problem described, of course, does not claim completeness. It is meant to illustrate the influence on the classification, of a limited number of similar attributes (the importance of the distinction between necessary and/or sufficient conditions), e.g. :

- *necessary, but not sufficient* : every bird lays eggs, but not every animal which lays eggs is a bird;

- *not necessary, but sufficient* : every animal giving birth to living creatures is a mammal, but there are other mammals;

- *not necessary, not sufficient* : not every bird can fly and not every animal which flies is a bird.

An overview of all the rules used in this classification problem (from PARK[1]), is supplied in Figure 3-16. The same problem is described in BORLAND[2], as the rule base of a (Turbo) Prolog program (See Figure 3-17).

1. See pp. 56-58 in: PARK, J. [83], *MVP-FORTH Expert System Toolkit, Knowledge-Based Inference Program*, Mountain View Press, Mountain View (Cal.), 1983.

2. BORLAND INTERNATIONAL INC. [86], *Turbo Prolog Owner's Handbook*, Scotts Valley, California, 1986, 221 pp.

```
[1] IF   NOT animal is a bird
    AND  animal has hair

    THEN animal is a mammal


[2] IF   NOT animal is a bird
    AND  animal gives milk

    THEN animal is a mammal


[3] IF   animal has feathers

    THEN animal is a bird


[4] IF   animal flies
    AND  animal lays eggs

    THEN animal is a bird


[5] IF   NOT animal is an ungulate
    AND  animal eats meat

    THEN animal is a carnivore


[6] IF   NOT animal is an ungulate
    AND  animal has pointed teeth
    AND  animal has claws
    AND  animal has forward eyes

    THEN animal is a carnivore


[7] IF   animal is a mammal
    AND  animal has hooves

    THEN animal is an ungulate


[8] IF   animal is a mammal
    AND  animal chews cud

    THEN animal is an ungulate
    AND  animal has even toes


[9] IF   animal is a mammal
    AND  animal is a carnivore
    AND  animal has tawny color
    AND  animal has dark spots

    THEN animal is a cheetah


[10] IF   animal is a mammal
     AND  animal is a carnivore
     AND  animal has tawny color
     AND  animal has bl. stripes

     THEN animal is a tiger


[11] IF   animal is an ungulate
     AND  animal has a long neck
     AND  animal has long legs
     AND  animal has dark spots

     THEN animal is a giraffe


[12] IF   animal is an ungulate
     AND  animal has bl. stripes

     THEN animal is a zebra


[13] IF   animal is a bird
     AND  NOT animal flies
     AND  NOT animal swims
     AND  animal has a long neck
     AND  animal is black/white

     THEN animal is an ostrich


[14] IF   animal is a bird
     AND  NOT animal flies
     AND  animal swims
     AND  animal is black/white

     THEN animal is a penguin


[15] IF   animal is a bird
     AND  animal flies
     AND  animal flies well

     THEN animal is an albatross
```

Figure 3-16. Rules for the animal classification problem

```
clauses

   animal_is(cheetah) if
      it_is(mammal) and
      it_is(carnivore) and
      positive(has,tawny_color) and
      positive(has,black_spots).

   animal_is(tiger) if
      it_is(mammal) and
      it_is(carnivore) and
      positive(has,tawny_color) and
      positive(has,black_stripes).

   animal_is(giraffe) if
      it_is(ungulate) and
      positive(has,long_neck) and
      positive(has,long_legs) and
      positive(has,dark_spots).

   animal_is(zebra) if
      it_is(ungulate) and
      positive(has,black_stripes).

   animal_is(ostrich) if
      it_is(bird) and
      negative(does,fly) and
      positive(has,long_neck) and
      positive(has,long_legs) and
      positive(has,black_and_white_color).

   animal_is(penguin) if
      it_is(bird) and
      negative(does,fly) and
      positive(does,swim) and
      positive(has,black_and_white_color).

   animal_is(albatross) if
      it_is(bird) and
      positive(does,fly_well).

   it_is(mammal) if
      positive(has,hair).
   it_is(mammal) if
      positive(does,give_milk).

   it_is(bird) if
      positive(has,feathers).
   it_is(bird) if
      positive(does,fly) and
      positive(does,lay_eggs).

   it_is(carnivore) if
      positive(does,eat_meat).
   it_is(carnivore) if
      positive(has,pointed_teeth) and
      positive(has,claws) and
      positive(has,forward_eyes).

   it_is(ungulate) if
      it_is(mammal) and
      positive(has,hooves).
   it_is(ungulate) if
      it_is(mammal) and
      positive(does,chew_cud).
```

Figure 3-17. Prolog clauses for the classification of animals

If this problem is translated into decision tables, it is obvious that some conditions also appear as actions elsewhere, thereby leading to a table hierarchy. The tree structure of the classification is reflected in the table structure (Figure 3-18), with different levels of tables, according to the subdivision in main categories (e.g. mammals, birds), subcategories (e.g. ungulates, carnivores), etc.

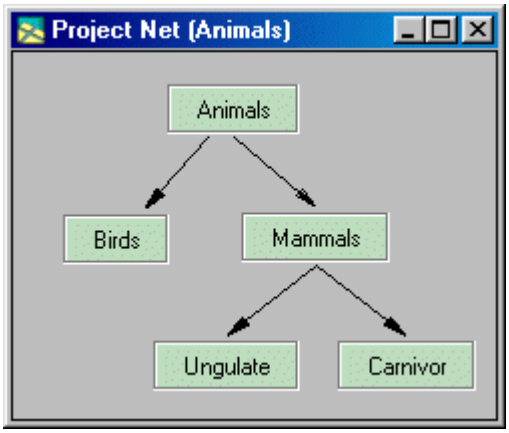


Figure 3-18. Table structure of animal classification

As the problem description was not meant to be complete, some holes will remain in the final decision tables (indicated with "...").

The main table (Figure 3-19), subdividing animals into birds and mammals (and calling the respective tables with the "^" symbol), refers to the first four rules, which can be combined into the following two decision rules :

[1] ^Bird **IF** Has feathers **OR** (Flies **AND** Lays eggs)
[2] ^Mammal **IF** (Has hair **OR** Gives milk) **MINUS RULE** 1

1. Skin	feathers	hair		...			
2. Flies	-	Y	N	Y		N	
3. Lays eggs	-	Y	N	-	Y	N	-
4. Gives milk	-	-	-	-	-	Y	N	Y	N
1. ^Birds	x	x	.	.	x	.	.	.	.
2. ^Mammals	.	.	x	x	.	x	.	x	.

Figure 3-19. Classification of animals

1. Chews cud	Y	N					
2. Has hooves	-	Y	N				
3. Eats meat	-	-	Y	N			
4. Has pointed teeth	-	-	-	Y	N		
5. Has claws	-	-	-	Y	N	-	
6. Has forward eyes	-	-	-	Y	N	-	-
1. ^Ungulate	x	x	.	.	.	.	.
2. Has even toes	x	.	.	.	.	.	.
3. ^Carnivor	.	.	x	x	.	.	.

Figure 3-20. Classification of mammals

1. Tawny color	Y			N
2. Skin pattern	dark spots	black stripes	...	-
1. Cheetah	x	.	.	.
2. Tiger	.	x	.	.

Figure 3-21. Classification of carnivores

1. Skin pattern	dark spots		black stripes	...
2. Long neck	Y	N	-	-
3. Long legs	Y	N	-	-
1. Giraffe	x	.	.	.
2. Zebra	.	.	x	.

Figure 3-22. Classification of ungulates

1. Flies	Y	N		
2. Flies well	Y	N	-	
3. Color	-	-	bl/w	...
4. Swims	-	-	Y	N	-
5. Long neck	-	-	-	Y	N	-
1. Ostrich	.	.	.	x	.	.
2. Penguin	.	.	x	.	.	.
3. Albatross	x	.	.	.	.	.

Figure 3-23. Classification of birds

A complete overview of all decision rules for these classification tables, is presented in Figure 3-24.

Classification of animals

[1] ^Bird	**IF** Has feathers **OR** (Flies **AND** Lays eggs)
[2] ^Mammal	**IF** (Has hair **OR** Gives milk) **MINUS RULE** 1

Mammal

[1] ^Ungulate	**IF** Chews cud **OR** Has hooves
[2] Has even toes	**IF** Chews cud
[3] ^Carnivore	**IF** (Eats meat **OR** (Has pointed teeth **AND** Claws **AND** Forward eyes)) **MINUS RULE** 1

Carnivore

[1] Cheetah	**IF** Tawny color **AND** Dark spots
[2] Tiger	**IF** Tawny color **AND** Black stripes

Ungulate

[1] Giraffe	**IF** Dark spots **AND** Long neck **AND** Long legs
[2] Zebra	**IF** Black stripes

Bird

[1] **Impossible**	**IF** **NOT** Flies **AND** Flies well
[2] Ostrich	**IF** **NOT** Flies **AND** Black & white **AND NOT** Swims **AND** Long neck
[3] Penguin	**IF** **NOT** Flies **AND** Black & white **AND** Swims
[4] Albatross	**IF** Flies **AND** Flies well

Figure 3-24. Decision rules for the classification of animals

3.4. First Aid to victims of poison

This example is left as an exercise to the reader. The following figure describes the problem for which a decision table has to be built (VERHELST [80]).

First Aid to victims of poison
1. In any case, first try to dilute the poison by administering large quantities of liquid (water, milk, ...). Then make sure the patient vomits. Repeat this dilute/vomit procedure until all poison is removed from the stomach of the patient. 2. The preceding general guideline must not be applied if the poison was a strong acid, strychnine or a petroleum product, nor when the patient lost consciousness. 3. If the poison was a strong acid, the poison has to be diluted with a small quantity of water and then neutralized as fast as possible. Then protect the stomach by administering normal kitchen oil. Make sure the patient does not vomit. 4. If the poison was strychnine, the procedure described under 1) should only be applied if the poison was taken only a few minutes ago. Otherwise, do not disturb the patient. 5. If the poison was a petroleum product, or if the patient lost consciousness, the vomiting procedure should definitely not be applied. Keep the patient warm and do not administer a liquid. 6. Independent of all previous points, try to find medical assistance as fast as possible.

Figure 3-25. First Aid to victims of poison

Try to apply the decision table construction method. On the **Prologa** distribution disk you can find a solution.

4. Theoretical Aspects Of Decision Tables As Seen By Prologa

Decision situations are characterized by three aspects : knowledge acquisition, validation (and maintenance), and decision making. In current knowledge based systems, little or no guarantees are usually present to support validation, change and complexity control.

In a vast majority of cases, the knowledge acquisition and validation processes are well served through the overview and communication abilities of well-structured decision tables. For this purpose, the decision table engineering workbench **Prologa** has been developed. This workbench incorporates rule based knowledge acquisition, table based verification, and adequate consultation interfaces.

This chapter gives a background on decision tables as they are used in **Prologa**. First, the basics needed to understand the advanced features of decision tables will be mentioned. The second section deals with the description of the specification language used in **Prologa**.

4.1. Decision tables and knowledge based systems

Decision tables and knowledge based systems show some striking similarities, although both approaches put strongly different emphases. While decision tables traditionally stress the representation facilities (with the resulting additional checking capabilities for completeness, consistency and correctness), knowledge based systems are mainly dealing with knowledge formulation (modularity, flexibility) and inference (performance, user friendliness).
In this manual it is argued that by using rule based design of decision tables, combined with a user friendly consultation mechanism, the strong points of both approaches can largely be combined :

- advantages of rule based knowledge acquisition (modularity, flexibility and simplicity);

- easy checking for completeness, consistency and correctness by designing decision tables;
- high performance of the search process;
- user friendly question driven interface.

As a lot of knowledge based systems which are being built nowadays use the rule based paradigm to develop systems which are essentially deterministic decision trees, it seems that mainly two aspects of current commercial expert system shells are used : a *question driven user interface*, and second, a *rule based knowledge acquisition, representation and inference scheme*. Other facilities (uncertainty, complex inference strategies, explanation facilities, heuristics, inductive learning) are often not considered. This raises the question whether deterministic decision trees are expert systems (HAYWARD[1], VALIENTE[2]) or need expert system shells (see also LEITH[3]).

Irrespective of the answer to these questions, it seems useful to consider other alternatives to obtain both desired aspects (the user interface and the rule based design/representation/specification scheme) for handling deterministic decision situations. The use of decision tables (using a decision table engineering workbench) is a promising alternative, as it easily enables the designer to check for contradictions, inconsistencies, incompleteness, redundancy, etc. in the rule base (VANTHIENEN [86], MAES & VAN DIJK[4]), which is one of the major problems in building and maintaining expert systems (see e.g. LOVELAND & VALTORTA, SUWA, SCOTT & SHORTLIFFE)[5].

4.2. Rule based decision tables

Even if at first sight decision tables in their current form look almost the same as years ago, their use has changed a lot (see e.g. VERHELST [80], CODASYL [82], REILLY, SALAH & YANG[6], VANTHIENEN[7]).

A decision table is a tabular representation of a *procedural decision situation*, where the state of a number of conditions determines the execution of a set of actions. Not just any representation, however, but one in which all distinct situations are shown as columns in a table, such that every possible case is included in one and only one column (completeness and exclusivity).

An example of a decision table is presented in Figure 4-1.

---

1. HAYWARD, S. [85], *Is a Decision Tree an Expert System*, in : BRAMER, M. (Ed.), *Research & Development in Expert Systems*, Proc. Fourth Technical Conf. on Expert Systems, Cambridge University Press, 1985, 228 pp., pp. 185-192.

2. VALIENTE, G. [91], *Are Complete K-Trees Something More Than Decision Trees*, Sigart Bulletin, Vol. 2, No. 2, ACM Press, April 1991, p. 6.

3. LEITH, P. [90], *Formalism in AI and Computer Science*, Ellis Horwood Limited, Chichester, 1990, 225 pp.

4. MAES, R., VAN DIJK, J. [88], *On the Role of Ambiguity and Incompleteness in the Design of Decision Tables and Rule Base Systems*, ISRA Report 88/01, Universiteit van Amsterdam, 1988, 21 pp.

5. LOVELAND, D., VALTORTA, M. [83], *Detecting Ambiguity : An Example in Knowledge Evaluation*, Proc. Eighth Intl Joint Conf. on Artificial Intelligence, Karlsruhe, Aug. 1983, Vol. 1, pp. 182-184.

   SUWA, M., SCOTT, A., SHORTLIFFE, E. [84], *Completeness and Consistency in a Rule-Based System*, in : BUCHANAN B., SHORTLIFFE E., *Rule Based Expert Systems*, Addison Wesley Publishing Co., Reading (Mass.), 1984, pp. 159-170.

6. REILLY, K., SALAH, A., YANG, C. [87], *A Logic Programming Perspective on Decision Table Theory and Practice*, Data & Knowledge Engineering, 87(2), pp. 191-212.

7. VANTHIENEN, J. [88], *Een moderne kijk op beslissingstabellen*, Informatie, December 1988, pp. 912-937.

1. Quantity Ordered (Q)	Q<10	10<=Q<15			Q>=15
2. Travel Distance (D)	-	D<50	50<=D<100	D>=100	-
1. No Discount	x	-	-	-	-
2. Discount 2 %	-	-	-	x	-
3. Discount 5 %	-	-	x	-	-
4. Discount 10 %	-	x	-	-	x
5. Railway Transport	-	-	-	-	x
6. Road	x	x	x	x	-
7. Bill Type A	x	x	x	x	-
8. Bill Type B	-	-	-	-	x

Figure 4-1. Example of a Decision Table

The tabular representation of the decision situation is characterized by the separation between conditions and actions, on one hand, and between subjects and conditional expressions, on the other. Every table column (decision column) indicates which actions should (or should not) be executed for a specific combination of condition states. The condition oriented approach of the decision table makes it very useful to *display* procedural knowledge, with such advantages as : overview, readability, easy checking for consistency and completeness. Most of the common validation problems in rule based systems (see e.g. NGUYEN et al.[8], AYEL[9], LIU & DILLON[10]) can easily be solved using decision tables, e.g. redundant rules, conflicting rules, subsumed rules, unnecessary conditions, circular rules, missing rules or combinations, unreferenced attribute values, illegal attribute values, dead end clauses.

4.3. The notation scheme of the decision table

The decision table is represented as a table which is split in two by a double line, both horizontally and vertically, resulting in four quadrants. The horizontal line divides the table in a condition part (above) and an action part (below). The vertical line divides subjects and entries in the stub (left) and the entry part (right) respectively. As you can see in Figure 4-2, the resulting quadrants are : condition stub, action stub, condition entries and action entries.

8. NGUYEN, T., PERKINS, W., LAFFEY, T., PECORA, D. [87], *Knowledge Base Verification*, AI Magazine, 8(2), 1987, pp. 69-75.

9. AYEL, M. [88], *A Conceptual Model for Consistency of Knowledge Bases*, in : O'SHEA, T & SGUREV, V. (Ed.), *Artificial Intelligence III : Methodology, Systems, Applications*, North-Holland, 1988, pp. 75-82.

10. LIU, N., DILLON, T. [88], *Detecting of Consistency and Completeness in Expert Systems using Numerical Petri Nets*, in : GERO, J. & STANTON, R. (Ed.), *Artificial Intelligence Developments and Applications*, North-Holland, 1988, pp. 119-134.1

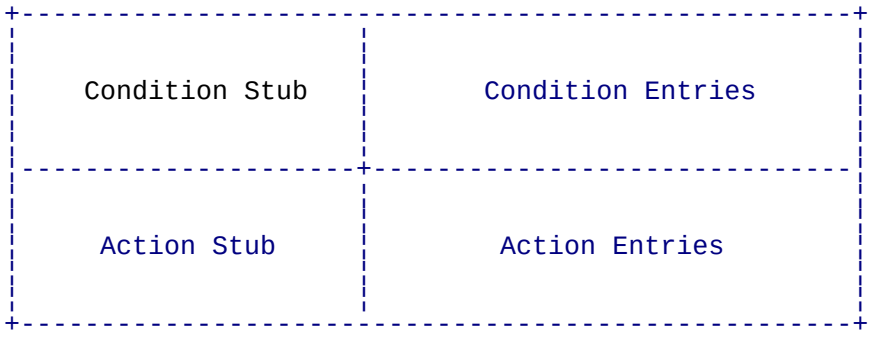


Figure 4-2. Quadrants of a Decision Table

This strict separation between conditions and actions is not always as simple as it looks :

- Some actions (initializations, bound actions) *have to be* executed before testing certain conditions. This problem can often be solved by using initializations (possibly condition subtables), but this results in a quite complex notation. If the problem cannot be solved this way, the table will have to be split in subtables;

- Some actions *can* already be executed after testing one or more conditions. This "rising" of actions (called *hoisting*) has the advantage that the relation with the conditions involved is illustrated more clearly. However, in general this mixing of conditions and actions will result in complex tables, thus loosing the overview. After all, since putting the action earlier is not strictly required because there are no order restrictions, this is already an attempt to optimize the table.

The entries part consists of columns (with condition states and action values) separated by a vertical line from the first different condition state. A column then contains a state for each condition or a contraction of states which yields the same result (with eventually "irrelevant" ("-") if this is the case for all states), followed by the resulting value for each action.

The order of the columns shows that only *single hit tables* are taken into account, in other words, each situation is present in only one column and, consequently, the columns will not interfere with each other. This excludes the use of the so called *multiple hit* tables, where a particular situation can be present in several (partially overlapping) columns, such that the order of the columns is determining their application area, which strongly reduces the overview and the validation possibilities.

If each column only contains simple states (no contractions or irrelevant conditions), the table is called an *expanded* decision table (*canonical form*), in the other case the table is called a *contracted* decision table (*consolidated form*). The transition from one form to the other is defined as *expansion* (*rule expansion*) and *contraction* (*consolidation*) respectively.

The condition names or action names in the stub can refer to other tables (subtables). The replacement of these references by the tables themselves, the *junction* of tables, is called (*table*) *expansion*. The reverse process, the *division* into subtables, is defined as *factoring*.

Some combinations of conditions may be *impossible*, in other words, they *cannot* occur. Such combinations may be deleted from the table (see further). Keep in mind that only real impossibilities are to be deleted, combinations that *should not* occur must stay in the table, since at one moment or another this might be the case (according to Murphy's Law).

4.4. Kinds of tables

In practice one has to distinguish between different kinds of tables, with the decision grid chart at one end of the spectrum and the decision table at the other end.

The most important criterion when distinguishing tables, is the question whether all columns are mutually exclusive (*single hit* versus *multiple hit*). In a single hit table each possible combination of condition can be found in exactly one (one and only one) column. This makes an unambiguous use of the table possible.

If the columns are not exclusive, the first hit rule will often be used. This rule states that the *first hit* (from left to right) will determine which set of actions has to be executed, thus preventing contradictions. Another possibility is that *all hits* are used to determine the set of actions to be executed. In this case, each hit from left to right can add actions (not mentioned by previous columns) or delete actions (contradiction with previous columns) to the set. This is the procedure applied for decision grid charts. In both cases (first hit versus all hits) the same combination of conditions can occur in different columns of the table. As a result the overview over the columns is lost, and with it, the simplicity of inspection. For these reasons we do not consider these tables to be decision tables.

Based on these considerations, we propose the following subdivision:

1. *multiple hit tables* (tables with non-exclusive columns)

   a) *all hits*
      the rule table or *decision grid chart* (table representation of the (action oriented) rule base) that serves as a basis to construct the decision table;

   b) *first hit*
      the "classic" multiple hit decision table as end product, has to be evaluated from left to right;

2. *single hit tables* (decision tables)

   a) *expanded*
      the condition oriented table representation of all single decision columns, used to check whether the table is correct and completely filled out;

   b) *contracted*
      the compact, condition oriented, table representation of all decision columns.

This grouping does not imply that one form is always better than the others. It has been mentioned that the decision grid chart (rule base) primarily has a specification function, and that the expanded table has a verification function. When constructing decision tables we will use both forms in this order, as steps in the process leading to the contracted table. In this context MAES & VAN DIJK[11] discuss the *lifecycle* of the decision table, distinguishing between 'construction time', 'test time' and 'interpretation time' decision tables (respectively corresponding to the types 1[a)], 2[a)] and 2[b)]).

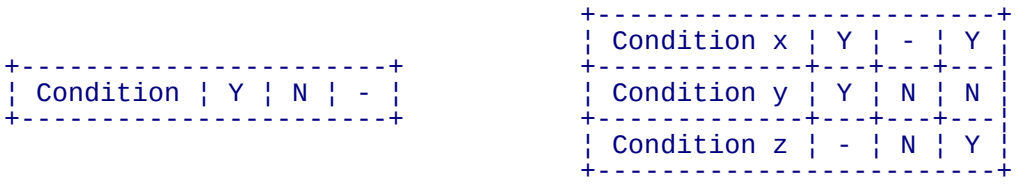
11. MAES, R., VAN DIJK, J. [88], *On the Role of Ambiguity and Incompleteness in the Design of Decision Tables and Rule Base Systems*, ISRA Report 88/01, Universiteit van Amsterdam, 1988, 21 pp.

4.5. Detailed discussion of form, contents and pragmatics of the decision table

Over the years the decision table has been subject to several adaptations and extensions. These changes dealt with both contents and cosmetics. The numerous extra features cause a loss of simplicity and uniformity. The effect is that the power and the applicability of the technique are rather reduced, instead of enlarged. Therefore it is recommended to respect a number of simplifications and standards. The following paragraphs impose a number of constraints to the use of the decision table technique. The constraints deal with the form as well as with the contents of the tables which are used (see also VERHELST [80], CODASYL [82]). These restrictions mainly emanate from the need to use the decision table as a well structured tool for the application area :

- *Exclusivity and completeness of the columns* *(Single hit tables)*

  The decision table, defined as a *mapping* of the Cartesian product of the condition states to the Cartesian product of the action values by which every condition combination is mapped onto one and only one action configuration, has to meet the demand of completeness and exclusivity with respect to. the columns. Therefore, each combination of conditions has to be included in one and only one column of the decision table. If this is not the case, the validation and the adaptation of the table will be next to impossible. This excludes the use of the multiple hit tables (with partially overlapping columns), where the following ambiguities and incompletenesses are possible (which often results in the agreement that the columns should be evaluated from left to right) :



- *Multi-valued states* *(Extended entry conditions)*

  The distinction between tables with limited, mixed or extended entries (limited, mixed- or extended-entry tables) is outdated. The condition part consists essentially of a number of conditions with a number of values ("states") for these conditions. Whether a condition happens to take several (mutually exclusive) values or only two (type boolean) is irrelevant. The argumentation that all tables with extended entries can be converted to limited entries (and thus do not have to be considered), neglects the modeling advantages that come with the higher level of the extended entry table (conciseness, manageability, abstraction power, overview). Moreover, the implementation with limited entries will always result in numerous impossibilities, since the different states should be mutually exclusive. This disadvantage weights heavier than the representational advantage obtained from the use of one symbol states (e.g. Y/N).

- *Exclusivity and completeness of the states* *(No ELSE-column)*

  Each possible value of a condition has to be included in one and only one condition state. This means that the set of states for a condition has to obey the requirement for completeness and exclusivity concerning the states (VERHELST [80, p. 11]). To obtain completeness, an ELSE-state for a condition may be defined. This state (called OTHER to prevent confusion with the ELSE-column) then contains all values of this condition that were not mentioned before. This

does not mean that this state is a waste basket in which all kinds of hidden combinations of conditions are put, as it was the case for the ELSE-column.

- *Contraction of condition states* *(Group-oriented contraction)*

  Columns or groups of columns that only differ in the state value for one condition and that contain the same actions, are joined as much as possible. This is not only the case if all states of a condition lead to the same action configuration, which renders the entry irrelevant ("-"), but also if (groups of) consecutive states with the same action configuration occur. The states may simply be joined by a connector ("OR").

  Examples :

```
                  +-------------------------------+
                  ¦ Color ¦ Black OR blue ¦ other ¦
                  +-------------------------------+

+--------------------------------------+     +--------------------------+
¦ Distance ¦ A<=10 OR 10<A<=15 ¦ A>15 ¦  =  ¦ Distance ¦ A<=15 ¦ A>15 ¦
+--------------------------------------+     +--------------------------+
```

- *Tree structures* *(Top-down readability)*

  Only tree structured tables are taken into account. A tree structured table is a table that can be read top-down (stepwise refinement) by continuing to choose from the relevant condition states until a specific column (traditionally called "rule") is reached. This excludes the use of the so called multiple-hit tables (with overlapping columns), that have to be evaluated from left to right, as well as the use of the ELSE-column. In this case the decision table is a straightforward representation of the *decision tree*. This eliminates "rule ambiguity" (more than 1 column satisfied) and simplifies testing for completeness. The tree structure also implies that the condition combinations occur from left to right in lexicographical order, in other words that the states of the lowest conditions vary first.

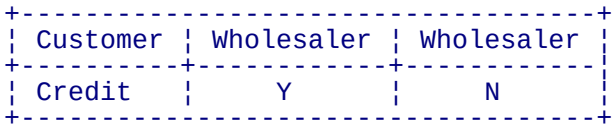
- *Concise representation* *(Block-oriented notation)*

  In order to obtain a maximal resemblance to the decision tree, it is advised that each node (condition entry) of a path is represented only once in the table, so that it is easier to read and to understand the table. Therefore, consecutive equal condition states (repeating themselves on the same row) with the same value for the higher conditions are only included once. In addition, this choice never makes the table larger, but in most cases considerable smaller, and this is an important concern when using decision tables.

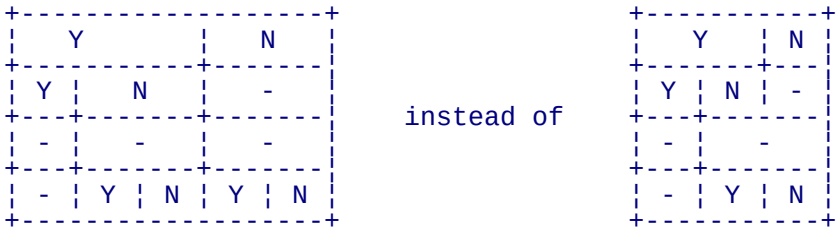
  The following notation is therefore preferred :

```
+------------------------+
¦ Customer ¦ Wholesaler ¦
+----------+------------¦
¦ Credit   ¦  Y  ¦  N    ¦
+------------------------+
```

  instead of :



Furthermore, the visual interpretation of the tree-principle means that a condition entry in the table (a "block") can never be enlarged by a following condition, but can only be split into other condition entries, depending on the relevant states of this last condition (if there are any). It can sometimes save place and time to violate the tree-notation by combining adjacent equal entries *with different parents* starting from some conditions (if this causes no ambiguities), exactly as adjacent branches in a decision tree can be brought together again. This way equal (parts of) paths only have to be written once. Nevertheless, the effect on the readability is quite unfavorable. Therefore each vertical line has to continue, once that it started, to the bottom of the table without interruption :



- *Predefined actions* *(Refined action-entries)*

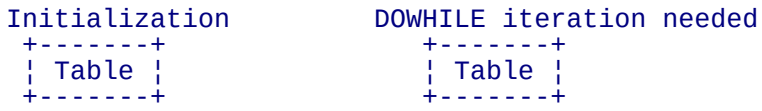
  Actions can only take a specific set of predefined values, e.g. : execute (x), do not execute (-), unreferenced (.), contradiction (?), ... This restriction is derived from the need for a simple (automatic) manipulation and validation of decision tables. An additional advantage is that all action entries are one symbol entries and thereby easy to represent in the table. After finishing and validating the table (and only then) actions can be contracted.

- *Subtables* *(Closed subtables)*

  All subtables are of the *closed* type, this means that after ending a subtable the calling table regains control (METZNER & BARNES [77, p. 41]). This PERFORM-binding, in contradiction to the GOTO-binding where each subtable explicitly has to indicate the paths to follow, is essential to the use of the decision table as an one-entry-one-exit structure element. Two types of (possibly recursive) subtables are possible : the *action subtable* which is a further specification of a certain action (comparable to a PROCEDURE or SUBROUTINE in programming) and the *condition subtable* which determines the value of a condition (comparable to a FUNCTION in programming).

- *Selection structure* *(No initialization or repeat actions)*

  A decision table is the representation of a complex multiple selection. It should therefore not include initialization or iteration facilities. By considering the decision table to be a *structure element*, initialization columns or actions can be represented as a sequence, and repeat actions can be represented as an iteration :



Other structure elements can be prevented by using table calls. The so called bound actions (actions that have to be executed before testing a certain condition) can be obtained by referring to a condition subtable where the action can be included as initialization. Moreover, a table can refer to itself as subtable. This is not a repeat structure, but a recursive call.
Within the table as structure element *nesting* can occur. The following actions could for instance occur : selections (IF-THEN-ELSE statements, nested tables), sequences (compound statements) or iterations. It should be clear that usually there is not enough room available and that the readability of the table is put under heavy fire. It is therefore recommended to realize such nesting only through procedures and functions.

- *Indication of impossibilities* *(Contracted impossibilities)*

Some combinations of condition states are impossible because of the nature of the problem, such that the state value of a condition may be implied by state values of higher conditions. If this is the case, there are different ways to indicate the existence of impossibilities :

a) assign to a *supplementary action* : "impossible". This may be practical for the construction phase, but the impossible combinations result in a final table crowded with columns that do not occur anyway.

b) *deletion* of the impossible columns. This frees the table of the redundant columns, but puts (at least with manual construction) a heavy burden on the demand for completeness because there is no indication where something was deleted. Furthermore, this deletion causes contraction problems because no minimal table width is obtained (see. VANTHIENEN [86]).

c) *deletion* of the impossible columns *with indication* of the possible (implied) states with !, * or (). This is historically the most common method in the literature, but this approach is only suited for "limited entry" conditions. In this case there is an indication that something is impossible, but for more than two states it cannot be indicated unequivocally what exactly is implied. Moreover, the same contraction problems occur as for sub b).

d) *contraction* of the impossibilities.
In this case, impossibilities are contracted with the neighboring (possibly all other) states. This results in tables of minimal width. Only the naming of the resulting states can sometimes be misguiding : it is possible that an irrelevancy is the indication of one or more implied states (see. the meaning of "-" as "does not *have to* be tested" versus "*must* not be tested").

e) *contraction* of the impossibilities *with indication* of the impossible states. The impossibilities are then contracted, but it is indicated which of the states are impossible.

4.6. Formal Definition of the decision table

We end this basic introduction to decision tables by giving a more formal definition.

In a decision table all distinct situations are shown as columns in a table, such that every possible case is included in one and only one column (completeness and exclusivity).

"*A decision table is a table, representing the exhaustive set of mutual exclusive conditional expressions, within a predefined problem area.*" (VERHELST [80])

The tabular representation of the decision situation is characterized by the separation between conditions and actions, on one hand, and between subjects and conditional expressions, on the other hand. Every table column (decision column) indicates which actions should (or should not) be executed for a specific combination of condition states.

Given :

$CS = \{CS_i\}$ (i=1..knum), a set of condition subjects;

$CT = \{CT_i\}$ (i=1..knum), a set of condition domains,
with CT_i : the domain (type) of condition i, i.e. the set of all possible values of condition subject CS_i
(type is integer, real, boolean, enumeration or subrange);

$C = \{C_i\}$ (i=1..knum), a set of condition state sets,
with $C_i = \{S_{ik}\}$: an (ordered) set of condition states S_{ik}, where each condition state is a logical expression concerning the elements of CT_i, which determines a subset of CT_i such that the set of all these subsets constitutes a partition (completeness and exclusivity constraint);

$AS = \{AS_j\}$ (j=1..anum), a set of action subjects;

$A = \{A_j\}$ (j=1..anum), a set of action value sets,
with A_j : the set of action values, which is, by assumption, equal for every action subject, viz. {"execute", "do not execute", "undefined"},

the decision table (with conditions $\{CS_i\}$ (i=1..knum) and actions $\{AS_j\}$ (j=1..anum)) can then be defined as follows (CODASYL [82]) :

The decision table is a function from the Cartesian product of the condition states C_1 x ... x C_{knum} to the Cartesian product of the action values A_1 x ... x A_{anum}, by which every condition combination is mapped onto one (completeness) and only one (consistency) action configuration.

The problem logic can then easily be represented by columns in a table. For ease of legibility, the columns are ordered such that the states of the lower conditions vary first.

The decision table is then a compact tabular representation of a lexicographically ordered set of decision columns, which for every condition combination uniquely identify all actions to be executed.

5. Description Of The Specification Language

That the use of natural language in specifications (procedures, requirements, descriptions) often goes hand in hand with numerous shortcomings (not to mention the lack of overview), can be deduced from the following list of problems that often occur (MEYER[1]) :

. **Noise** : the presence in the text of a element that contains no relevant or no new information .

  Important variants :
  - **Redundancy** : repetition of information;
  - **Remorse** : the presence of a restriction on the description of a certain element, but which is not included where the element is defined, but where it is used;

. **Silence** (incompleteness) : the existence of an aspect of the problem that is not treated in the text;

. **Contradiction** : the presence of two or more elements which are not conform with each other;

. **Ambiguity** : the presence in the text of an element that makes it possible to interpret an aspect of the problem in at least two different ways;

. **Forward references** : the presence in the text of an element that makes use of aspects of the problem that are only defined later in the text.

These are sufficient reasons to introduce a more *formal specification*.

5.1. Foundations of a specification language

For the description of the action oriented decision specifications it is sufficient to indicate for each action the set of condition combinations for which the action has to be executed (or should not be executed). This basically results in the following two expressions :

action j : ('**True**', set of conditions)
action j : ('**False**', set of conditions)

1. MEYER, B. [86], *Over het Gebruik van Formalismen in Specificaties 1*, Informatie, 28(5), Mei 1986, pp. 450-456.

If an action should not be executed for a certain situation, this has to be mentioned explicitly. If nothing is specified, the value "undefined" is assumed.

The set of conditions can refer to a column of the expanded table (intersection of the states of the diverse conditions, indicated by the AND-operator) or to a set of columns (indicated by the OR-operator). Unless specified otherwise, the OR is always inclusive : the one or the other or both. This is often indicated as ... and/or ...

In its most elementary form the specification language can consist of the logical operators AND, OR and the expression :

```
          logical value
action <---------------- set of conditions
```

where the logical value (**True** or **False**) indicates whether the action should or should not be executed for the given set of conditions.

This is illustrated with an example of a simple decision table in Figure 5-1.

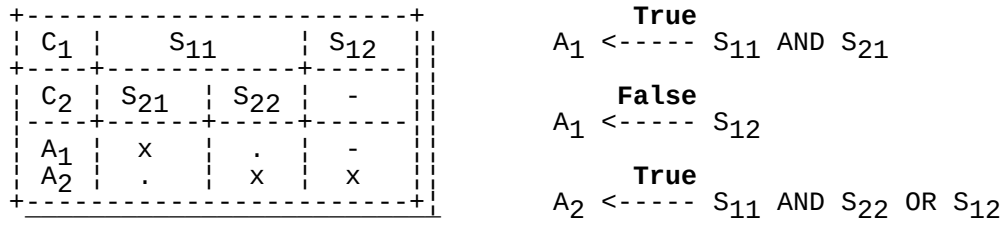


Figure 5-1. Example of a simple decision specification language

Because of the higher priority of AND compared to OR, no parentheses are required. Note that common condition combinations can be separated (distributive property), but then parentheses have to be used to change the priority of the operators :

$$\ldots S_{11} \text{ AND } S_{31} \text{ OR } S_{21} \text{ AND } S_{31} = \ldots (S_{11} \text{ OR } S_{21}) \text{ AND } S_{31}$$

The OR-operator is then in fact used in two different meanings :

- union of sets of the same condition, e.g. S_{11} OR S_{12};
- product of sets of different conditions,
  e.g. S_{11} OR $S_{21} \equiv S_{11}$ AND S_{21} OR S_{11} AND S_{22} OR S_{12} AND S_{21}.

Furthermore a logical expression does not have to mention all conditions. The union of *all* possible states of a condition can simply be deleted, so that e.g. (for two states) :

$$S_{12} \text{ AND } S_{21} \text{ OR } S_{12} \text{ AND } S_{22} = S_{12} \text{ AND } (S_{21} \text{ OR } S_{22}) = S_{12}$$

This kind of language, which forms the basis of the unequivocal construction of decision tables, was described first in VERHELST [69] (with the implicit assumption of the **True**-value and with NOT as supplementary operator).

5.2. Requirements of a specification language

A specification language must enable to analyze and better understand the problem situation in a simple manner. Moreover, these specifications have to be clear for both the system that will work with the specifications as well as for the designer. DEMUYNCK & MEYER[2] present a list of requirements to which each specification language has to conform.
These requirements are taken into account in **Prologa** :

- **Problem-oriented** : not the solution, but the problem itself should be described. Therefore supplementary operators are introduced in **Prologa**. These operators must allow for a strict modeling of the problem situation, e.g. : general rules, exceptions, restrictions;

- **Unambiguous** : One of the goals of the decision specification language is describing the ambiguities and imperfections unequivocally;

- **Abstraction and generality** : the usage of logical concepts (IF-THEN rules) makes the language suited for several classes of (procedural) decisions;

- **Modularity** : the problem is described in autonomous logical expressions (decision rules), which can be related;

- **Syntax and semantics** : the construction blocks of the specification can be described simple (syntax) and have a unequivocal meaning (semantics);

- **Theoretical basis** : the specification language and the specification method are based on a clearly defined theoretical basis, viz. set theory and relational algebra;

- **Readability and simplicity** : the usage of elements and constructions from natural language makes the specifications easy to understand and to learn;

- **Power and compactness** : an extended set of operators is available. Operands and operators can be represented more compact. For this purpose the names of conditions and actions are replaced by their sequence number (1,2,...), while the condition states are denoted in a similar way by their corresponding letter (a,b,c...). Each operator has its own symbol, e.g. * for AND, + for OR. This allows the experienced user to work more compact. The expression

```
              True
action 1  <----  condition 1 state a OR condition 2 state b
```

  can then be written down (short notation) as :

```
     True
  1 <---- 1a OR 2b
```

---

2. DEMUYNCK, M., MEYER, B. [81], *A la Recherche de la Spécification Idéale*, 01 Informatique, Nr. 150, Mai 1981, pp. 65-70.

Two supplementary simplifications are possible :
(i) condition states of a specific condition can only be connected by OR, because they are mutually exclusive (the intersection of 1a AND 1b ≡ ø (empty)) and thus can be joined to form an enumeration, e.g. : 1abc;
(ii) actions that are specified for the same combinations of conditions, can be joined and connected by AND. Connecting actions by OR is not unequivocal and therefore not allowed.

The expression then takes the following form :

```
        logical value
actions <------------ condition combinations
```

This form of the elementary specification language is used (with implicit assumption of the **True**-value) in the PRODEMO system (MAES, VANTHIENEN & VERHELST [81]).

In another notation this can be written as :

If combination of conditions **Then** actions

. **Availability of a workbench** : to make the specification easier, an automatic system has to be present that allows to specify, validate, analyze, store, edit and process logical expressions in an interactive way. The basic elements of such a workbench (**Prologa**) are depicted in Figure 5-2.

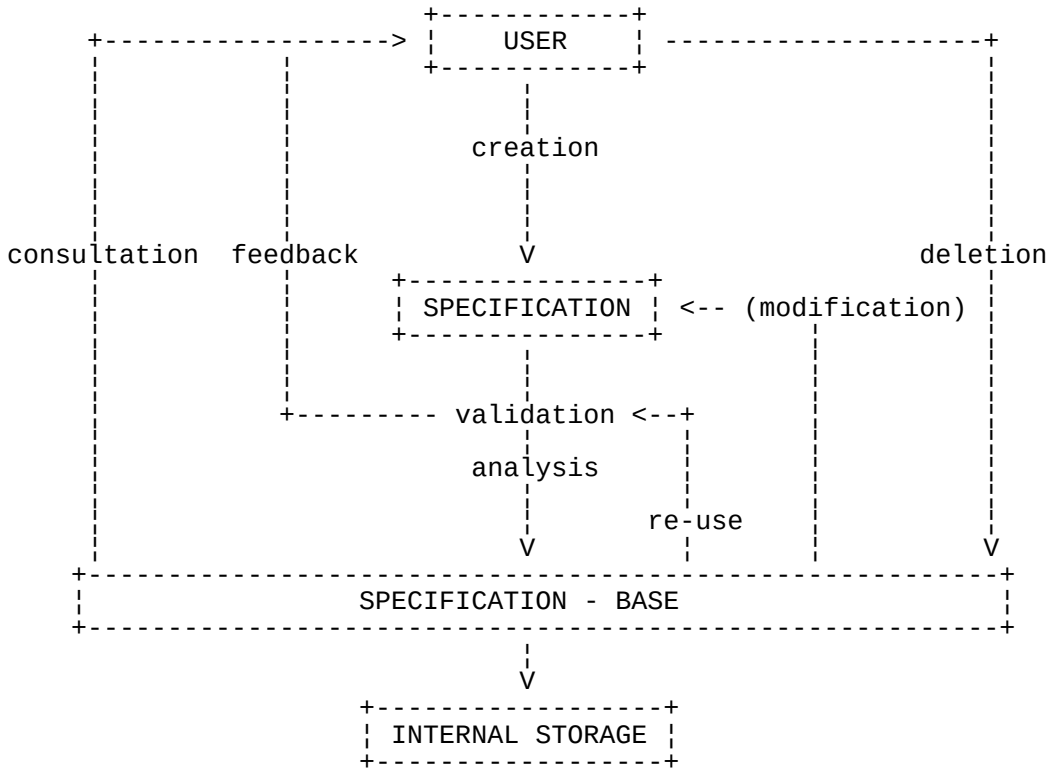


Figure 5-2. Support requirements of the specification language

5.3. Logical, causal and other operators

This section introduces some elements from logic and Boolean algebra. This is done primarily for two reasons. First, it forms the foundation of the theory behind decision tables. Second, understanding this section will enable the user to get more out of **Prologa** and understand better how the workbench really functions. However, even without understanding this section it is possible to use **Prologa** successfully.

Based on the text (if any) and on the list of conditions, condition states and actions, the problem situation is represented in the form of decision rules. For the description of the action oriented decision specifications, it is sufficient to indicate the set of condition combinations for which the action(s) has (have) to be executed (or should not be executed). For reasons of compactness, the names of conditions and actions are replaced by their sequence number (1,2,...), while the condition states are denoted in a similar way by their corresponding letter (a,b,c...).

This basically results in the following expression :

action_part	if_part	condition_part

To resemble closely the decision situation that has to be modeled, the specification language has to offer more and also more powerful facilities than only the operators IF, AND, OR. Such a more refined specification language is proposed by MAES [81, pp. 177 et seq.].
In this section this specification language gets a theoretical foundation. Also, some adjustments and extensions are introduced[3] to improve the generality and the manageability. VANTHIENEN [86] indicates how (the processing of) the presented language can be implemented. This implementation is brought into practice with the discussion of the decision rules as they are used in the **Prologa** system.

A decision situation usually does not consist of a collection of independent descriptions, but contains several levels of structure, e.g. general rules, exceptions, ... Therefore, the specification language makes use of logical expressions with different levels of significance. Basically two levels are distinguished: **definite** and **preliminary** consequence. General (preliminary) rules can be overruled by later specifications (exceptions), while a definite rule can not be neutralized (and may even lead to contradiction messages). In combination with the ONLY operator, a **possible** consequence is also provided (indicating that complementary elements are not allowed).

5.3.1. Basic Logical Operators

The elementary operators AND, OR are logically sufficient to express all possibilities, but will often lead to cumbersome and/or unnatural specifications. Additional logical operators from set

3. The major changes refer to (cfr. infra) :
   - Addition of the logical operators MINUS, NAND, NOR and the enumerative operands ALL, NONE;
   - Replacement of the exclusiveness notation ([...]) by the more universal ONLY operator;
   - Generalization of the "ref:" and ":ref" limitators to the RULE operand, which additionally enables various other references;
   - Generalization of the relations between actions : MAXIMUM 1, JUST 1, MINIMUM i, MINIMUM i AND MAXIMUM j.

theory are therefore provided, which enable powerful and concise specification facilities, although they can be reduced to the basic operators AND, OR. Furthermore, the majority of these extended operators has a natural language equivalent, thereby simplifying the specification task.

The complete set of operators, with their Dutch counterparts is given (in decreasing order of priority from left to right) by :

NOT (niet)	AND (en)	OR (of)
	MINUS (min)	XOR (xof)
	NAND (nen)	NOR (noch)

X MINUS Y ≡ X AND NOT Y
X XOR Y ≡ (X OR Y) MINUS (X AND Y)
X NAND Y ≡ NOT (X AND Y)
X NOR Y ≡ NOT (X OR Y)

Common formulation of the basic operators

NOT

- not
- always ... except ...
- in all cases ... unless ...

MINUS

- minus
- unless, except, apart from, ...
- excluding ...

XOR

- either ..., or ...
- in one and only one of the following two cases
- ... or ..., unless both occur together

NAND

- if at least one of both cases does not occur
- except for the joint occurrence of ...
- unless the following cases occur together

NOR

- neither ... nor ...
- if none of both cases occurs

5.3.1.1. The NOT operator

The NOT operator indicates the negation (complement) of an action or a condition (combination). This operator only refers to one operand and therefore receives highest priority (unless parentheses are being used).
In the CONDITION PART, the negation of one or more condition states means the union of the other states (because of the completeness requirement for condition states).

NOT 1a = 1bc...

NOT 1ab = NOT (1a OR 1b) = NOT 1a AND NOT 1b
= 1bc... AND 1ac...
= 1c...

The negation of (combinations of) condition states is subject to the following calculation rules :

NOT NOT X ≡ X

X AND NOT X ≡ ø (empty)
X OR NOT X≡ Ω (universe) *{law of the excluded third}*

NOT (X AND Y)≡ NOT X OR NOT Y
NOT (X OR Y) ≡ NOT X AND NOT Y *{DE MORGAN's laws}*

According to these simple reformulations, an expression containing NOT can always be reduced to a combination of AND, OR operators and a negation of elementary condition states.

In the ACTION PART, NOT can be used to denote that an action should not be executed, as indicated previously by the **False** operator.
It is therefore useful to replace both notations (**True**/**False**) by a single operator : <-, where the logical value is implicitly indicated through the possible presence of a NOT operator :

```
                                    True
    action  <-  ... ≡  action <----- ...

                                    False
NOT action  <-  ... ≡  action <----- ...
```

Because actions can not be connected with OR (ambiguity), the form

NOT (... AND ...) ≡ NOT ... OR NOT ...

is not allowed. The reverse, NOT (... OR ...), would be possible, but in order to avoid confusion, no parentheses are allowed in the action part. This implies that the NOT operator in the action part must be repeated :

1 AND NOT 2 AND NOT 3 <- ...

Common formulation for NOT

- not
- always ... except ...
- in all cases ... unless ...

In Dutch :

- niet
- altijd ... tenzij ...
- in alle gevallen ... behalve ...

5.3.1.2. The MINUS operator

The MINUS operator is defined as the intersection of the first operand with the complement of the second operand and can always be reduced to a combination of AND, OR operators :

X MINUS Y ≡ X AND NOT Y

The distinction between MINUS and NOT is clearly shown when NOT is rewritten as :

NOT X ≡ Ω MINUS X

> Common formulation for MINUS
>
> - minus
> - unless, except, apart from, ...
> - excluding ...
>
> *In Dutch :*
>
> - min
> - tenzij, behalve, uitgezonderd ...
> - met uitsluiting van ...

Two special cases :

X MINUS (X AND Y) ≡ X AND NOT (X AND Y)
≡ X AND (NOT X OR NOT Y)
≡ X MINUS Y

X MINUS (X OR Y) ≡ X AND NOT (X OR Y)
≡ X AND (NOT X AND NOT Y)
≡ ø (empty)

The operators AND and MINUS have equal priority and are therefore evaluated from left to right. As opposed to the operators AND, OR which are commutative and associative, the following important properties hold for the MINUS operator :

X MINUS Y ≠ Y MINUS X	{not commutative}
(X MINUS Y) MINUS Z ≠ X MINUS (Y MINUS Z)	{not associative}
X AND Y OR X MINUS Y = X	{complementary}

5.3.1.3. The XOR operator

This operator indicates an exclusive OR situation between two operands : one of the two, but not both of them together. The normal OR on the other hand is inclusive : one of the two or both. Therefore by definition :

X XOR Y ≡ (X OR Y) MINUS (X AND Y) ≡ X MINUS Y OR Y MINUS X
≡ X AND NOT Y OR NOT X AND Y

Common formulation for XOR

- either ..., or ...
- in one and only one of the following two cases
- ... or ..., unless both occur together

In Dutch :

- ofwel ..., ofwel ...
- in een en slechts een van volgende gevallen
- ... of ..., tenzij beide zich samen voordoen

The XOR and OR operators have equal priority and are therefore evaluated from left to right. Some important properties :

X XOR Y = Y XOR X {commutative}
(X XOR Y) XOR Z ≠ X XOR (Y XOR Z) {not associative}

Moreover, the multiple XOR operator (X XOR Y XOR Z) does not bear the meaning of : one of the operands, but not all (some) of them together, unless a function would be implemented of the form XOR (X,Y,Z,...). In order to obtain the same effect, the following expressions can be used, depending on the desired result :

(X OR Y OR Z) MINUS (X AND Y AND Z) {not all of them together}
(X OR Y OR Z) MINUS (X AND Y OR X AND Z OR Y AND Z)
{not some of them together}

5.3.1.4. The NAND operator

This operator (mainly used in computer hardware terminology) indicates the negation of a conjunction :

X NAND Y ≡ NOT (X AND Y)
≡ NOT X OR NOT Y

Similar to the XOR operator, the intersection of both operands is excluded. However, the XOR operator additionally requires one of the operands to be fulfilled :

X XOR Y = (X NAND Y) AND (X OR Y)

Common formulation for NAND

- if at least one of both cases does not occur
- except for the joint occurrence of ...
- unless the following cases occur together

In Dutch :

- indien minstens een van beide zich niet voordoet
- behalve bij het gelijktijdig voorkomen van
- tenzij volgende gevallen zich samen voordoen

The NAND and AND operators have equal priority and are therefore evaluated from left to right. Some important properties :

X NAND Y = Y NAND X {commutative}
(X NAND Y) NAND Z ≠ X NAND (Y NAND Z) {not associative}

Because the NAND operator does not correspond to a simple natural language equivalent (as one specific word), its use is limited. Moreover, it can easily be represented as a negation of AND structures. Furthermore, like the XOR operator, NAND is not unequivocally defined for more than two operands.
This operator therefore has been included mainly for the sake of completeness.

5.3.1.5. The NOR operator

Like NAND is the complement (negation) of AND, NOR is the complement of OR. With this difference that NOR is much more useful, as it corresponds to a simple natural language equivalent.

X NOR Y ≡ NOT (X OR Y)
≡ NOT X AND NOT Y

Common formulation for NOR
- neither ... nor ... - if none of both cases occurs
In Dutch :
- (noch) het ene, noch het andere - indien geen van beide zich voordoet

The NOR and OR operators have equal priority and are therefore evaluated from left to right. Some important properties :

X NOR Y = Y NOR X {commutative}
(X NOR Y) NOR Z ≠ X NOR (Y NOR Z) {not associative}

As the operator is not unequivocally defined for more than two operands, an extended construction will have to be used in that case (negation of OR structures).

5.3.2. Extension to the limitative operator ONLY

The ordinary logical expression indicates which actions have to be executed for which condition combinations. It is however not mentioned :

. what should happen with the OTHER ACTIONS in the specified case;

. what should happen with the specified actions in the OTHER CASES.

For these purposes the ONLY (ENKEL) operator can be used, which indicates a non-execution for the condition combinations or actions **not** referred to in the expression. The ONLY operator can be added to the condition part and/or the action part and leads to the following general notation (specifications between [...] are optional) :

```
IF condition combination
THEN actions
    [NOT other actions      {ONLY operator in action part}]
[ELSE NOT actions           {ONLY operator in condition part}]
```

5.3.2.1. The ONLY operator in the condition part

actions <- ... ONLY condition combinations

The use of ONLY here indicates that for the specified condition combinations (only), the designated actions should be executed and that the actions should not be executed in the remaining cases.
The operator therefore combines the following two expressions :

actions <- condition combinations
NOT actions <- NOT condition combinations

This formulation represents a conventional "IF AND ONLY IF" situation and indicates that the condition combinations (X) constitute a *necessary* (¬Y <- ¬X) *and sufficient* (Y <- X) *condition* for the execution of the actions (Y) (Figure 5-3).

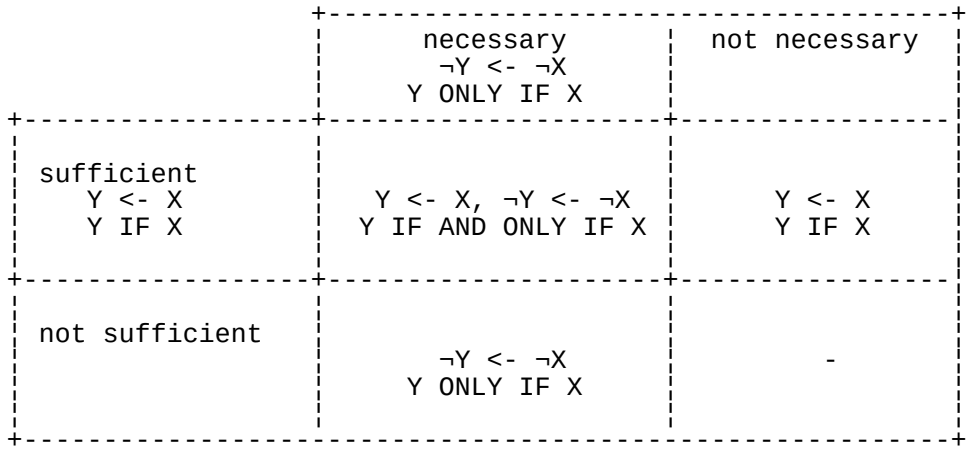


Figure 5-3. Necessary and/or sufficient conditions

Common formulation for ONLY (condition part)

- If and only if ...
- Only if ...
- Should only be executed in the following cases ...
- A necessary and sufficient condition is ...

In Dutch :

- Als en slechts als ...
- Enkel indien het volgende zich voordoet ...
- Een noodzakelijke en voldoende voorwaarde is ...

It is clear that only one ONLY operator can occur in the condition part, which therefore receives lowest priority. The ONLY operator then refers to all subsequent condition combinations (inside the parentheses, if any). The operator, however, does not have to be the first operator, but may refer to only a part of (AND) combinations.
Example :

actions <- 1a AND ONLY (2a OR 3a) =
actions <- 1a AND (2a OR 3a)
NOT actions <- 1a AND NOT (2a OR 3a)

In this case the application area of the ONLY operator is limited to the columns of 1a instead of the complete table.

5.3.2.2. The ONLY operator in the action part

ONLY actions <- condition combinations

The use of ONLY here indicates that for the specified condition combinations, the designated actions (only) should be executed and that the remaining actions should not be executed.
The expression is in fact a short notation for :

actions AND NOT other actions <- ...

This formulation indicates that the actions (Y) constitute a *necessary* (Y <- X) *and sufficient* (¬Y' <- X) *consequence* of the condition combinations (X) and that the remaining actions (Y') therefore should not be executed (Figure 5-4).

Common formulation for ONLY (action part)

- These and only these actions should be executed if ...
- Only the following actions should be executed ...
- The only possibility in that case is ...

In Dutch :

- Deze en enkel deze acties moeten gedaan worden ...
- Moeten enkel volgende acties uitgevoerd worden ...
- De enige mogelijkheid in dat geval is ...

Also in the action part only one ONLY operator can occur and in order to avoid confusion it should be in front (referring to all subsequent actions). Otherwise the operator would make no sense.

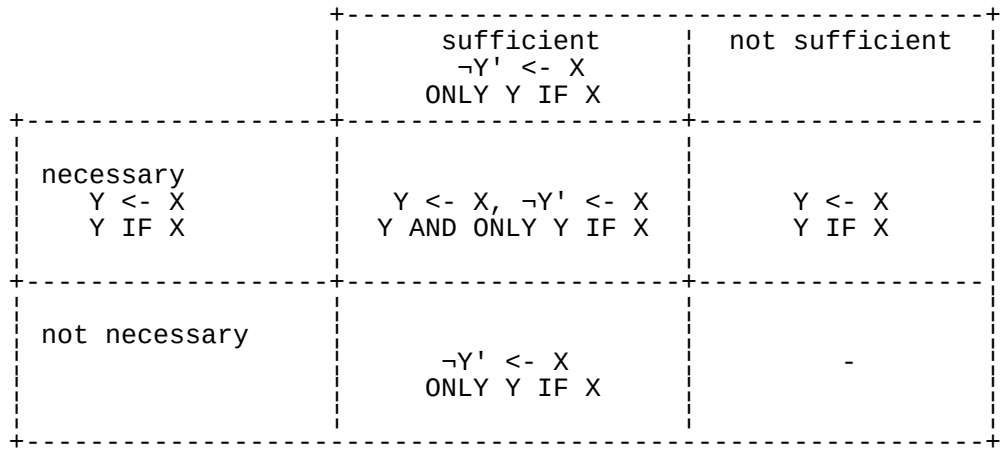


Figure 5-4. Necessary and/or sufficient consequences

The general effect of the ONLY operator is indicated in the following tables (Figure 5-5).

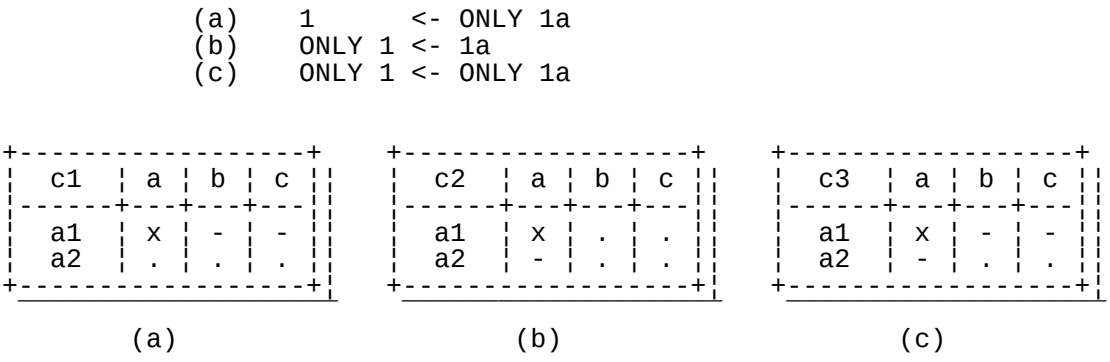


Figure 5-5. Results of the ONLY operator

5.3.3. Extension to refined causal operators

Specifying the procedural decision situation requires a specification language which closely matches natural language and its nuances. A decision situation usually does not consist of a

collection of independent descriptions, but contains several levels of structure, e.g. general rules, exceptions, ...

This also means that logical expressions could be assigned different levels of significance. Operators are therefore supplied to provide expressions with relative priorities, in the sense that certain expressions (general rules) can be overruled by later specifications (exceptions), or that an expression can not be neutralized.

In order to keep the notation and the understandability of the specification language simple, two priority levels are distinguished : **definite** en **preliminary** consequence. In combination with the ONLY operator a third[4] causal operator is provided : **possible** consequence.

This distinction leads to the following basic operators :

DEFINITELY IF	*(definitief indien)*
[GENERALLY] IF	*([voorlopig] indien)*
POSSIBLY IF	*(mogelijk indien)*

For reasons of user friendliness a number of synonyms are accepted to clarify the priority nuances : *certainly*, *invariably*, *exceptionally* for ***definitely if***; *normally*, *provisionally* for ***generally if***.

5.3.3.1. The operator DEFINITELY IF

... DEFINITELY IF ...

The operator *definitely if* (represented by <-<-) is used to indicate that, for the specified condition combination, the set of actions should always and unconditionally be executed (or, in the negative case, should not be executed). This specification can not be overruled anymore by other specifications.

> Common formulation for DEFINITELY IF
>
> - Must always be executed if ...
> - Should never occur if ...
> - Irrespective of any other specification, ...
> - ... should in all cases ...
>
> *In Dutch :*
>
> - Moet altijd uitgevoerd worden indien ...
> - Mag nooit voorkomen als ...
> - Wat ook elders gespecificeerd wordt, ...
> - ... moet in ieder geval ...

Note :
Every attempt to override such a definite decision rule by means of another definite rule (e.g. using an ONLY operator (cfr infra)), will cause a contradiction :

4. Cfr. in the same order : imperative, logical and potential consequence (MAES [81, p. 180]).

1 AND 2 DEFINITELY IF 1a
NOT 1 DEFINITELY IF 1a AND 2b

This is indicated in the decision table using a "?" symbol[5].

5.3.3.2. The operator (GENERALLY) IF

... IF ...

This operator (represented by <-) is used to indicate a preliminary consequence : for the specified condition combination, the set of actions will normally have to be executed (unless stated otherwise in the remaining specifications). This makes the operator especially useful for representing general rules and exceptions (in this order).
In numerous practical situations (procedures, texts) this operator is often meant where the stronger <-<- operator is used. Legal texts, e.g., commonly show this ambiguity, by first putting a general rule as an unconditional statement and then providing several exceptions and deviations in subsequent articles.

Common formulation for (GENERALLY) IF

- Normally this has ...
- As a general rule ...
- If nothing else is mentioned ...
- Unless otherwise specified, in principle ...

In Dutch :

- Normaal moet ...
- Als algemene regel ...
- Indien niets anders vermeld wordt ...
- Tenzij anders gespecificeerd, moet in principe ...

Note :
Overriding such a general decision rule by means of another rule will not cause a contradiction. If the overriding rule if of the form DEFINITELY IF, it will always receive a higher priority (no matter which rule comes first). If the overriding rule is of the form GENERALLY IF, the most recent specification will hold, in order to enable the specification of general rules, exceptions, exceptions to exceptions, e.g. :

1 GENERALLY IF 1a
ONLY 2 GENERALLY IF 1a AND 2a

The meaning of a specification is then influenced by the (relative) order of appearance (and the presence of other specifications). This dependency upon order slightly reduces the potential for consistency checking, as exceptions do not explicitly have to be registered as exceptions and contradictory rules are therefore always treated as modifications or additions.
A solution to this problem might be to have exceptions explicitly refer to the corresponding general rule(s) and to treat all other modifications as contradictions.

---

5. In fact the contradiction will be detected and signaled when entering the decision rule. It is not necessary to display the decision table itself to discover some contradictions or ambiguities (in specifications, texts, procedures, etc.).

5.3.3.3. The operator POSSIBLY IF

... POSSIBLY IF ...

This operator (represented by (<-)) is meaningful only when used in combination with the ONLY operator. It indicates that a certain action is possible for the specified condition combination. This does not imply that the action has to be executed. But when used with the ONLY operator (e.g. ONLY ... POSSIBLY IF), it indicates that the other actions should NOT be executed. The POSSIBLY IF operator is therefore only useful to specify in which cases actions should NOT be executed.
The combination of an ONLY operator and a POSSIBLY IF operator is not essential and can be replaced by (specifications between [...] are optional) :

[ONLY] actions [ONLY] POSSIBLY IF ... =

[NOT other actions DEFINITELY IF ... {ONLY in action part}]
[NOT actions DEFINITELY IF NOT ... {ONLY in condition part}]

Common formulation for POSSIBLY IF

- Only the following actions can occur ...
- Only in these cases, ... could ...
- Is only possible if ...
- The only possibility in that case is ...
- Can only be executed if ...

In Dutch :

- Kunnen enkel volgende acties zich voordoen ...
- Enkel in deze gevallen kan ...
- Is alleen mogelijk indien ...
- De enige mogelijkheid in dat geval is ...
- Mogen slechts uitgevoerd worden indien ...

5.3.3.4. The causal operators combined with the ONLY-operator

If a causal operator is used in combination with the ONLY operator, it is not only indicated which actions have to be executed, but also which actions should not be executed. This latter part always leads to an expression of the same priority type as the original expression (*definitely* or *preliminary*), except for the POSSIBLY IF operator, which always leads to an expression of the type DEFINITELY IF.
Example :

actions ONLY POSSIBLY IF ... ≡

actions POSSIBLY IF ...
NOT actions DEFINITELY IF NOT ...

The distinction between necessary and sufficient conditions, refined with an indication on the definite or preliminary character of the specification, results in the various alternatives shown in Figure 5-6.

	necessary		not necessary	
	preliminary	definitely	preliminary	definitely
sufficient	(GENERALLY) ONLY IF Q <- P ¬Q <- ¬P	DEFINITELY ONLY IF Q <-<- P ¬Q <-<- ¬P	(GENERALLY) IF Q <- P	DEFINITELY IF Q <-<- P
not sufficient	-	ONLY POSSIBLY IF Q (<) P ¬Q <-<- ¬P	(POSSIBLY IF) (Q (<) P)	-

Figure 5-6. Restrictive and definite character of the conditions

Similar refinements can be defined for the consequences (the actions to be executed). In that way, a distinction can be made between necessary versus not necessary consequences, preliminary versus definite consequences, and sufficient versus not sufficient consequences (excluding the remaining actions).
This results in the various alternatives shown in Figure 5-7.

	sufficient		not sufficient	
	preliminary	definitely	preliminary	definitely
necessary	ONLY q (GENERALLY) IF Q <- P ¬Q' <- P	ONLY q DEFINITELY IF Q <-<- P ¬Q' <-<- P	(GENERALLY) IF Q <- P	DEFINITELY IF Q <-<- P
not necessary	-	ONLY q POSSIBLY IF Q (<) P ¬Q' <-<- P	(POSSIBLY IF) (Q (<) P)	-

Figure 5-7. Restrictive and definite character of the consequences

In addition, the restrictive character of the conditions and of the consequences can be combined into one decision rule :

ONLY q DEFINITELY IF AND ONLY IF p

in order to indicate that q and only q should be executed if (and only if) p holds, and that q should not be executed if p does not hold.

Common formulation for ONLY

DEFINITELY :
- (only) ... should always be executed if (only) ...
- if and only if ...
- cfr ONLY, DEFINITELY IF

In Dutch :

- (enkel) ... moet in ieder geval (enkel) uitgevoerd worden indien ...
- indien en enkel indien ...

GENERALLY :
- This (and only this) action is normally executed if ...
- Unless otherwise specified, only ...
- cfr (GENERALLY) IF

In Dutch :

- Deze (en enkel deze) actie wordt in regel uitgevoerd indien ...
- Tenzij anders gespecificeerd, wordt enkel ...

POSSIBLY :
- (only) ... can (only) be executed if ...
- cfr POSSIBLY IF

In Dutch :

- (enkel) ... mag (enkel) uitgevoerd worden indien ...

5.3.4. Extension to relations between expressions using the RULE operand

It occurs that certain specifications are only applicable inside (or outside) the (condition) domain of other expressions, e.g. exceptions with regard to general rules. To this end, references can be made to (the rule number of) other expressions (using the RULE ... operand), as all rules are numbered (automatically) in increasing order.

The reference operand RULE (*REGEL*) ... can then be used, analogous to the other operands, in combination with all logical operators (AND, OR, NOT, MINUS, XOR, ...). In order to keep the references simple and to avoid deadlock situations (mutual relations), references can only be made to previous rules. The object of the reference is the condition part of the referred rule (without ONLY), e.g. :

[x] ... <- condition combinations

...

[y] actions <- ... OR RULE x ...

= actions <- ... OR (condition combinations in [x])

The major applications of the RULE operand emanate from the association with the logical operators AND, OR, NOT :

. **Confinement** : restricting an expression to (*within*) the application domain of another expression. This formulation is especially suited for the specification of EXCEPTIONS, as the RULE operand can refer to a (preceding) general rule : ... condition combinations AND RULE ...

. **Enlargement** : extending an expression with the application domain of another expression : ... condition combinations OR RULE ...

. **Exclusion** : excluding the application domain of another expression. This formulation is especially suited for the specification of a REMAINDER, as the RULE operand easily enables to exclude all (preceding) specifications : ... condition combinations MINUS RULE ...

Common formulation for RULE

- As far as the above conditions also hold
- Except for the cases mentioned in ...
- Unless otherwise specified ...
- ... or in the cases mentioned above
- Apart from these exceptions ...

In Dutch :

- Voorzover tevens voldaan is aan bovenstaande voorwaarden ...
- Met uitsluiting van de in ... bepaalde gevallen
- Tenzij anders werd vermeld ...
- ... of in de hierboven vermelde gevallen
- Behoudens deze uitzonderingen ...

5.3.5. The enumerative operands ALL, NONE and ALWAYS

ALL (alle) NONE (geen) ALWAYS (altijd)

In some cases all (or none) of the actions should be executed, or some actions should always be executed (unconditionally). In order to avoid this enumeration of actions or condition states, the following enumerative operands can be used to simplify the notation :

ALL IF ... ≡ 1 AND 2 AND 3 ... IF ...
NONE IF ... ≡ NOT 1 AND NOT 2 ... IF ...
... IF ALWAYS ≡ ... IF 1abc ...

This shorthand notation also offers an additional advantage, as it is *independent from the number of conditions and actions* (even when no conditions or actions are present). E.g. if an expression containing ALL is present and an action is added during the modeling process, the expression also holds for this new action (which would not have been the case if the original actions were enumerated).

5.3.6. Describing condition or action dependencies

Analogous to the relations between conditions and actions (condition combinations leading to the execution of actions), dependencies might exist between certain conditions or certain actions. Some combinations of condition states might imply the state of another condition and some actions might imply other actions. Relations between conditions can easily be expressed in the specification language. Relations between actions are not supported explicitly, but can be expressed in other ways.

5.3.6.1. Relations between conditions

If a relation between conditions exists, the occurrence of a certain combination of values determines the value of some other condition (CODASYL [82, pp. 3-17]). This last value is implied by the other condition(s). The existence of implied condition states might be indicated using a special operator : IMPLIES (->) (MAES [81, p. 183]), which should be interpreted as IF ... THEN ..., as in the following example :

condition 1 : New customer ? (Yes, No)

condition 2 : Credit limit allowed ? (0, >0 ... <X, ...)

New customer = Yes -> Credit limit allowed = 0
or : 1a -> 2a

Implied condition states often result from the splitting of a single state set over several conditions. E.g. the representation of an extended entry (multi-valued) condition into various limited entry (Yes/No) conditions, leads to this type of dependencies, as the impossible combinations must be excluded (all states must be disjunct) :

Extended entry condition : Amount ? (<X, ≥X and <Y, ≥Y)

= Limited entry condition : 1. Amount <X ? (Yes, No)
2. Amount ≥X and <Y ? (Yes, No)
with : 1a -> 2b

It is clear that indicating the only possible condition states is equivalent to excluding the impossible condition combinations. In that way, the implications can easily be introduced in the specification language : impossible combinations are excluded by means of the indication IMPOSSIBLE in the action part of the decision rule :

X -> Y ≡ IMPOSSIBLE IF X AND NOT Y
≡ IMPOSSIBLE IF X MINUS Y

Particularly this last expression (using MINUS) clearly illustrates the meaning :
X implies Y indicates that the occurrence of X MINUS (without) Y is impossible.

Depending on the causal operator which is used, a distinction can be made between DEFINITELY IMPOSSIBLE and GENERALLY IMPOSSIBLE. DEFINITELY IMPOSSIBLE is the most common form here, as implications are usually unconditional and definite.

Moreover, IMPOSSIBLE receives a higher priority than the execution of (other) actions within the same priority class.

Using IMPOSSIBLE in combination with (ONLY) POSSIBLY IF, as in : CAN (ONLY) BE IMPOSSIBLE IF, is not supported and considered meaningless.

5.3.6.2. Relations between actions (not supported by Prologa)

If a relation between actions exists, the (non-)execution of a certain action also determines the (non-)execution of some other actions. These relations could again be indicated by means of the IMPLIES (->) operator :

action i -> action j AND action k AND NOT action l

The advantage which is obtained by using this operator for simple implications however is limited, as actions which belong together could as well be specified together, as in :

action AND other actions IF ...

or :

[x] action IF ...
[..] other actions IF RULE x ...

A special case of relations between actions consists of mutual exclusion. Some actions can exclude each other, meaning that only one of them should hold for each specific situation, e.g. (MAES [81, p. 183]) :

action i -> action j XOR action k

Exclusion mainly occurs because only limited-entry actions are provided, such that the various (disjunct) action values must be divided over several actions, which can not occur simultaneously. The exclusiveness could be indicated with a specification MAXIMUM 1 (action allowed), e.g. :

Discount (0%, 5%, 10%) corresponds with :

1. Discount 0%
2. Discount 5%
3. Discount 10%

1 AND 2 AND 3 MAXIMUM 1

If the additional requirement also exists that in all cases at least one (and only one) action should be indicated, the notation MAXIMUM 1 (≤1) could be replaced by JUST 1 (=1). Other restrictions might then also be used, such as : MINIMUM i (≥i), MINIMUM i AND MAXIMUM j (= BETWEEN i AND j).

These additional specifications would be added in the action part of a decision rule. A supplementary condition part might be provided, but in most cases the restriction will hold *definitely and unconditionally* :

actions BETWEEN i AND j ≡
actions BETWEEN i AND j DEFINITELY IF ALWAYS

The specification of mutual exclusivities mainly serves the validation process, but is not strictly required for construction purposes. It will therefore not be considered here any further.

5.4. Syntax of the Specification Language

The specification language, as it has been worked out in this chapter, consists of logical expressions, called decision rules, in which is indicated which actions have to be executed for which combinations of conditions. An overview of the syntax of decision rules in **Prologa** is given in Figure 5-8.

Although **Prologa** also supports the Dutch names of the operators and operands, we will only describe the syntax in English.

The syntax is defined by the Backus-Naur Form (BNF), with following meta-symbols (cfr WIRTH[6]) :

<...> : name of a sentence, or part of a sentence (nonterminal symbol)
::= : is defined as
[...] : optional (0 or 1 time)
{...} : iteration (0 or more times)
...¦... : or (exclusive alternatives)

All other symbols that are not surrounded by <...>, refer to terminal symbols (literals).

The resulting syntax of a decision rule can then be written as follows :

<decision rule> ::= <action part> [<causal operator> <condition part>]

<action part> ::= <action list> ¦ **all** ¦ **none** ¦ **impossible**

<action list> ::= [**only**] <action reference> { **and** <action reference> }
<action reference> ::= { **not** } <action>
<action> ::= 1 ¦ 2 ¦ ...

<causal operator> ::= **definitely if** ¦ [**generally**] **if** ¦ **possibly if**

<condition part> ::= <condition list> ¦ **always**

<condition list> ::= <term>
¦ <condition list> <or-operator> <term>
<term> ::= <factor>
¦ <term> <and-operator> <factor>
<factor> ::= <reference> ¦ (<condition list>)
¦ **not** <factor> ¦ **only** <factor>
<reference> ::= <condition reference> ¦ <rule reference>
<condition reference> ::= <condition> <state> { <state> }
<rule reference> ::= **rule** <rule number>
<or-operator> ::= **or** ¦ **xor** ¦ **nor**
<and-operator> ::= **and** ¦ **minus** ¦ **nand**
<condition> ::= 1 ¦ 2 ¦ ...
<rule number> ::= 1 ¦ 2 ¦ ...
<state> ::= a ¦ b ¦ ...

Figure 5-8. Syntax of the specification language

6. WIRTH, N. [77], *What Can We Do about the Unnecessary Diversity of Notation for Syntactic Definitions?*, Communications of the ACM, 20(11), Nov. 1977, pp. 822-823.

Decision Rule Syntax

While you are entering decision rules, you can activate a help screen that contains the syntax.

A decision rule consists of an action-part, an if-part and a condition-part, in this order.
In the following table the syntax is split in three parts, each part is represented by a column. The operators are listed in descending order of priority.

ACTION PART	**IF PART**	**CONDITION PART**
Impossible : **/**	1. dif (definitely if) : **!**	always : **#**
all : **@**	2. if (generally if) : **:**	
	3. pif (possibly if) : **?**	**0..9**
1..9		**a..f**
		rule : **.**
1. not : **-**		
2. and : *****		
2. only : **|**		

CONDITION PART
1. **( )**
2. not : **-**
3. and : *****
minus : \
nand : **$**
4. or : **+**
xor : **&**
nor : **%**
5. only : **|**

6. Reference Manual

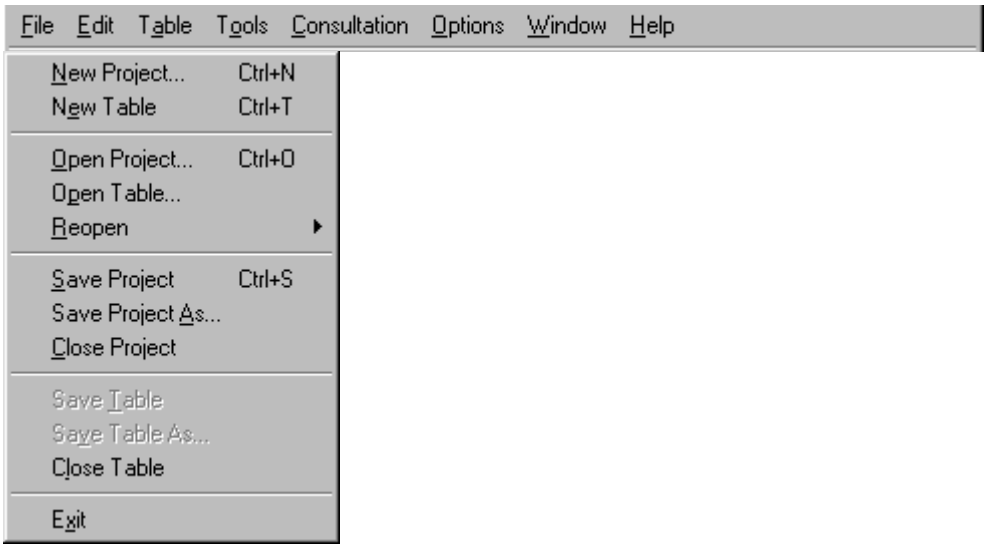
This reference manual has been split up in several parts. The first part, the ***Command Dictionary***, will explain all commands that are built into **Prologa**. The second part of this chapter, ***Defaults & Configuration***, deals with the computer requirements and the default settings of **Prologa**, where the third part, ***Files and Filenames***, will explain the meaning of the different file-types **Prologa** generates. ***Limitations and Hints*** is the fourth and final part of this chapter. It will help you to deal with some limitations still present in **Prologa** and will also give you some other useful hints.

6.1. Command Dictionary

This section will give an overview of the commands you can activate within **Prologa**. The commands are given in the order you will find them in the menu-system.

The menu contains the following commands:

6.1.1. File



When you select file in the main menu, the File pulldown menu contains the typical file operations.

6.1.1.1. New Project

New Project creates a new project database (.MDB) and a new project file (.PRJ). Upon creation, you will be prompted to enter a name and location for this project.

Prologa only deals with one project at a time. If the project has been changed during the session, **Prologa** will ask you whether the project should be saved before opening a new one.

After New Project, the next logical step to choose is 'New Table'.

6.1.1.2. New Table

When a project is open, the new table will be added to the project (upon creation, you will be prompted to enter a name for this table), else an isolated table will be created.

After New Table, the next logical step to choose is to input conditions and actions..

6.1.1.3. Open Project

6.1.1.4. Open Table

6.1.1.5. Save Project

6.1.1.6. Close Project

6.1.1.7. Save Table

6.1.1.8. Exit

6.1.2. Edit

6.1.2.1. Screen Capture

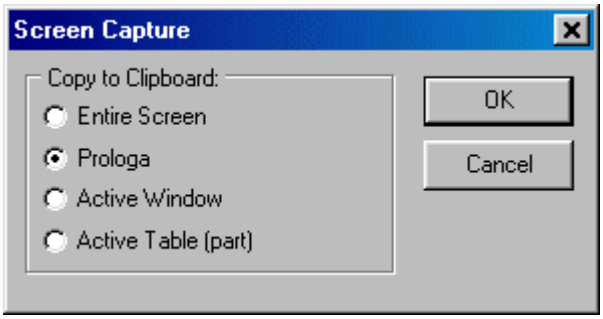
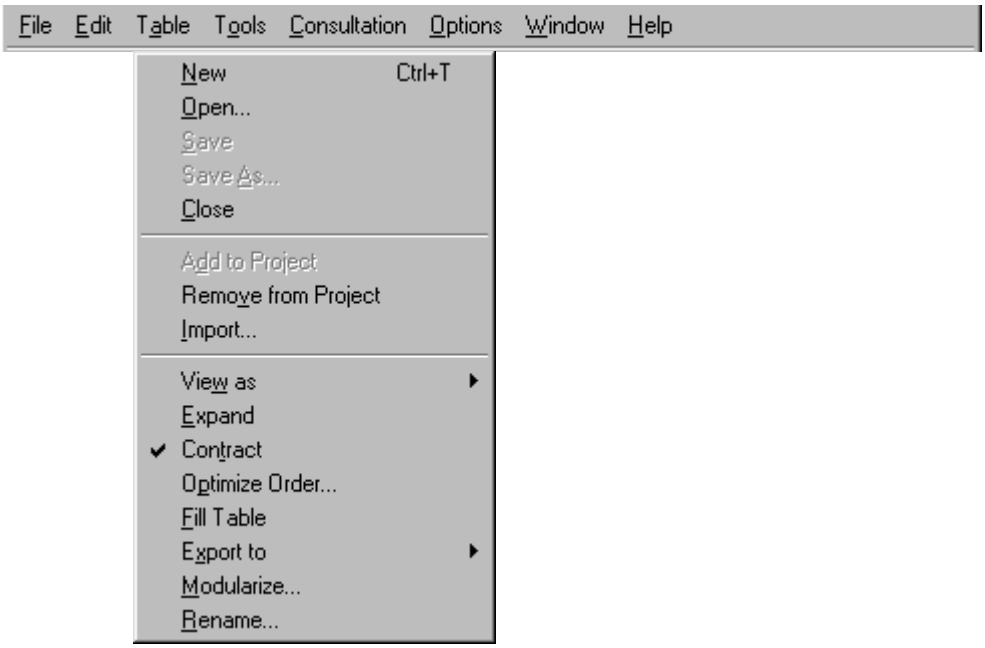
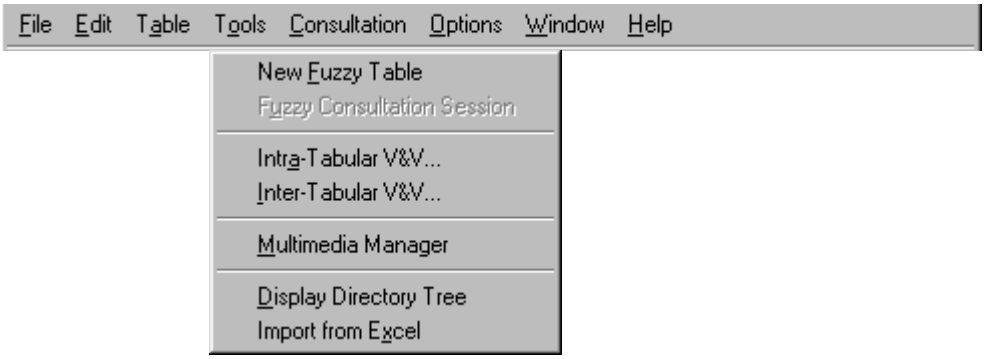


Figure 6-1. Capturing (part of) the Prologa screen

6.1.3. Table



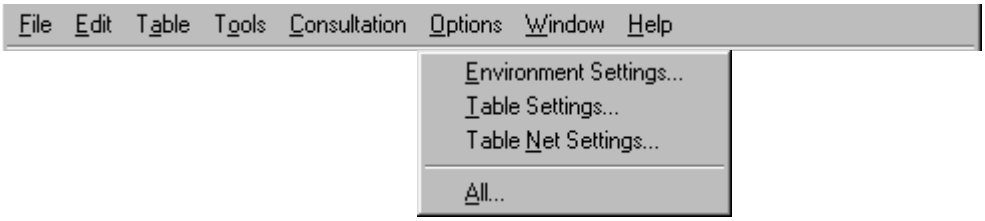
6.1.4. Tools



6.1.5. Consultation

6.1.6. Options

The commands in this pull-down menu are provided for maximal personalization of **Prologa**. The options pull-down menu consists of the following groups of topics:



Configuration defaults are provided in the PROLOGA.INI file (which must not be changed). All defaults can be customized using the options menu and will then be **valid for all following sessions**.

If you have changed some settings and you want to return to the **Prologa** default settings, use the default button in the options submenu.

6.1.6.1. Environment Settings

The Environment Settings allow you to change the directories where **Prologa** will store or look for projects and tables or where various export files will be written.

A. Project Directory

B. Table Directory

C. Log Directory

Several export possibilities are provided by **Prologa**. They will write text files to the Log Directory. The files that can be exported (with their extensions):

.DEC	decision table elements output
.PAS	decision table PASCAL code output
.COB	decision table COBOL code output
.C	decision table C code output
.JAVA	decision table JAVA code output
.E	decision table EIFFEL code output
.BAS	decision table VISUAL BASIC code output
.EXP	decision table minimal rules output
.EXP	decision table output to Aion 8.1 decision table
.DOC	decision table output to MS-Word table
.TXT	decision table as tree output

Table 6-1. Export File Types

6.1.6.2. Table Settings

Prologa allows you to customize the way a decision table is displayed. The following options can be set to adapt the table display to your preferences.

Start Contracted	ON
Join States	ON
Column Numbers	ON
Draw Shadow	ON
View Stub	ON
Black & White	OFF
Connect	‘ or ‘

Table 6-2. Table Settings and their defaults

A. Start Contracted

When this option is checked, the contracted table is always displayed when opening or starting a new table. This means that adjacent columns leading to identical action configurations are combined, thereby showing a better overview of the decision situation.

B. Join States

When this option is checked, adjacent equal condition states are displayed only once, thereby saving screen space. Otherwise all states are repeated in every column.

C. Column Numbers

When this option is checked, columns are provided with column numbers below the decision table.

D. Draw Shadow

When this option is checked, the table is displayed with a shadow at the right and at the bottom of the decision table.

F. View Stub

The stub is the left part of the decision table, containing the description of actions and conditions. For large tables, however, it might be useful not to include the stub of the decision table, thereby saving screen space.

G. Black & White

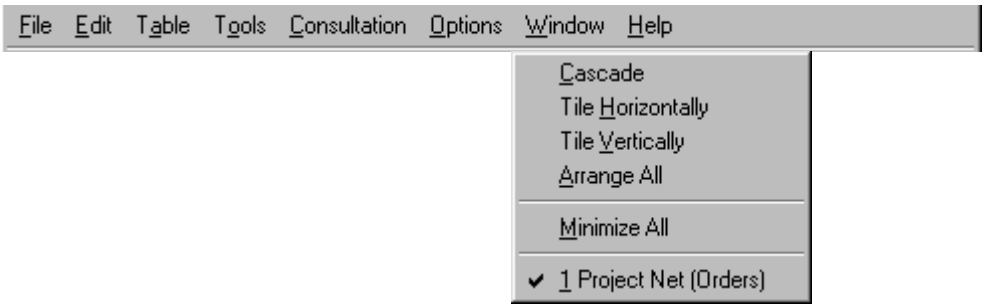
Check this option if you want a black & white display without disturbing the normal colors.

H. Connect

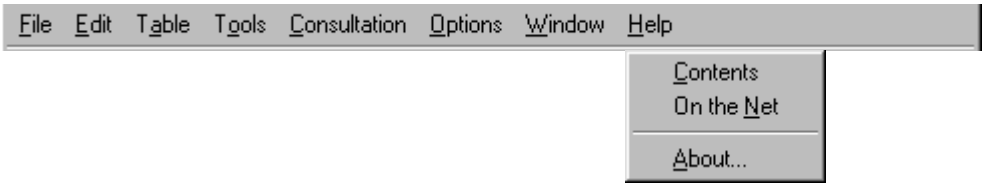
Adjacent states leading to identical action configurations are combined in one column and separated by this word or symbol. Note that this is only applicable for conditions with more than two states.

e.g. if the separator is ‘ ***OR*** ‘ and states ***b*** and ***c*** of a condition lead to identical results, they will be combined in the table into ***b OR c***.

6.1.7. Window



6.1.8. Help



6.1.8.1. About

When you select this command, a pop-up window will appear on the screen to provide you with more information on this version of **Prologa**.

6.2. Defaults & Configuration

See 6.1.6 Options.

6.3. Files and Filenames

This section will treat the file types generated by **Prologa** and also mentions which files you should have, together with their function.

6.3.1. File types used and created by Prologa

The main file types used by **Prologa** are the PRJ file (project file), MDB file (project database) and TAB file (internal representation of the decision table).

6.3.2. Files on the Prologa Disk

In the \PROLOGA directory :

PROLOGA.EXE
: The **Prologa** program code. The program is activated by typing PROLOGA, which may be followed by a table name.

PROLOGA.INI
: **Prologa** configuration file containing the default options.

PROLOGA.HLP
: **Prologa** help file.

…

In the \PROLOGA\PROJECTS directory :

Example project directories

in the \PROLOGA\TABLES directory :

HOLIDAYS.TAB
: The first *example*

ORDERS.TAB
CUSTOMER.TAB
EXECUTE.TAB
: *Example* of a decision table structure with three decision tables

ANIMALS.TAB
BIRDS.TAB
MAMMALS.TAB
CARNIVOR.TAB
UNGULATE.TAB
: The tables for the Animals Classification Problem

POISON.TAB
: The last *example* of a decision table.

6.4. Table Limitations and Hints

Figure 6-2 indicates which table limitations you may come across when using **Prologa**. These limitations are mainly due to memory constraints (or in order to keep related elements together on one screen). This section will also give some hints on how to deal with these limitations.

KMAX = 9	Maximum nr of conditions
KLENGTE = 255	Maximum nr of characters for a condition name
SMAX = 9	Maximum nr of states for each condition
SLENGTE = 255	Maximum nr of characters for a state name
TMAX = 4096	Maximum nr of condition combinations

AMAX = 20	Maximum nr of actions
ALENGTE = 255	Maximum nr of characters for an action name

BMAX = 127	Maximum nr of decision rules
GMAX = 1024	Maximum nr of columns in decision grid chart
MAXILEN = 255	Maximum nr of characters for a decision rule

Figure 6-2. Prologa Limitations & their implications

As Figure 6-2 shows, their are mainly three groups of limitations you should keep in mind. These three groups are dealt with in the following sections.

6.4.1. Condition Limitations

The three main limitations for conditions are: maximum nr of conditions, maximum nr states for each condition and maximum nr of condition combinations.

If more conditions are needed, try to divide the problem in subproblems. Put each of the subproblems in a subtable.

If more states are needed for a particular condition, the only thing to do is to split the variable in 2 or more parts.

Example: how to represent 12 months in **Prologa**:

```
condition 1. Yearhalf     States: a. First     b. Second
condition 2. Month         States: a. 1     b. 2     c. 3
                                   d. 4     e. 5     f. 6
```

The number of state combinations is limited. The number of combinations a particular decision table has (TNum) can be calculated as:

PRODUCT (statnum[i]) (i=1..knum)

where statnum[i] is the number of states for condition i, and where `knum` is the number of conditions in the table

6.4.2. Action Limitations

There is only one important limitation for actions: the maximum nr of actions. If more actions are needed, create an action subtable.

6.4.3. Rule Limitations

The two main limitations for rules are: maximum nr of decision rules and maximum nr of columns in the decision grid chart. If you need more rules, try optimizing the rules first.

Be aware that the use of **not** may lead to a large number of decision grid chart columns, if the negated part is highly complex (e.g. if it contains references to several previous rules).

7. Appendices

7.1. Appendix A: ERROR MESSAGES AND WARNINGS

7.1.1. Error Messages

Action & condition editing errors
- Cannot delete action that is still used in a rule
- Action index %d outside valid range
- No more than %d actions allowed
- Action name should not exceed %d characters
- Action name is missing
- Cannot move action: source and destination index are the same
- Size of expanded table cannot exceed %d columns
- Cannot delete condition that is used in a rule
- Condition index %d outside valid range
- No more than %d condition subjects allowed
- Name of condition subject should not exceed %d characters
- Name of condition subject is missing
- Reordering conditions resulted in error. Specified new order may be invalid
- Cannot move condition: source and destination index are the same
- State can only be added if condition subject is not used in a rule
- State can only be deleted if condition subject is not used in a rule
- State can only be moved if condition subject is not used in a rule
- Condition state index outside valid range
- No more than %d states allowed per condition
- Each condition subject should have at least %d states
- Condition state should not exceed %d characters
- Name of condition state is missing
- Reordering condition states resulted in error. Specified new order may be invalid
- Cannot move condition state: source and destination index are the same
- New order %s is invalid

Rule editing errors
- Rule index %d outside valid range
- No more than %d decision rules allowed
- Decision space limit has been reached
- Rule that is still referenced cannot be changed
- Rule %d would refer to a deleted rule
- Reference to later decision rule is not allowed
- Cannot move rule: source and destination index are the same

Rule parsing errors
- Illegal action part: character "%s".
- Action part should consist of IMPOSSIBLE only

- Expecting AND in action part: character "%s" found
- There is no action numbered %d
- Only one IF operator group allowed
- Action references can only range from 1 to %d
- No action part entered
- No condition part entered
- No parentheses allowed within action part
- Unmatched number of parentheses within condition part
- Condition part should consist of ALWAYS only
- Illegal condition part: character "%s".
- Illegal reference of condition states: character "%s".
- Character "%s" is not allowed
- Illegal sequence of parentheses within condition part
- Illegal last character in condition part
- Illegal last character in action part
- No reference to states for condition %d
- There is no condition numbered %d
- Double state reference for condition %d is not allowed
- State reference for condition %d is out of range
- Intersection empty, no combinations left for condition %d
- Decision rule too complex for remaining decision space
- Decision rule is too long: rephrase it
- Enumerating all states makes condition %d irrelevant
- There is no rule numbered %d: only previous rules allowed
- Reference to other decision rule is not a number: "%s".
- RULE references can only range from 1 to %d
- Action part should consist of ALL or NONE only
- No ALL or NONE allowed within condition part
- No OR/XOR/NOR operator allowed within action part
- No MINUS/NAND operator allowed within action part
- No ALWAYS allowed within action part
- Only one ONLY allowed within action part
- Only one ONLY allowed within condition part
- Action part should start with ONLY
- Double reference to action %d is not allowed
- No RULE reference allowed within action part
- No IMPOSSIBLE allowed within condition part

Fill by mouse errors
- Table column index %d outside valid range
- This action entry is definite and cannot be altered
- This entry contains definite entries and cannot be altered
- Impossible action entries cannot be filled
- Opposite definite entries remain a contradiction
- Columns with partial contraction cannot be filled. Expand table
- Decision table should be in fill mode before action entries can be filled in
- Decision table without conditions or actions cannot be filled in

Display errors
- Decision table cannot be displayed with current contraction options.
- Decision table cannot be displayed at this size.

Reordering errors
- %d is not within the valid range of %d..%d
- Expecting number: character "%s" found
- Expecting , or - between numbers: character "%s" found
- Duplicate integer value found

Optimal order errors

- Expecting following format: row number, column number
- Illegal condition number(s) specified
- This (or the opposite) relation was already specified
- Not enough memory: only the first %d solutions are shown
- Optimization cancelled: displayed results may be suboptimal

7.1.2. Warnings

Rule parsing warnings

- If this rule is added, a contradiction with a previous rule would be created, by combining:
  - definitely execute action
  - definitely do not execute action

  See "?" indication in displayed table.
- No IF, no conditions; "! ALWAYS" assumed
- "?" is normally used with ONLY operator
- The ONLY after IMPOSSIBLE has no effect
- IMPOSSIBLE IF ALWAYS may omit all columns
- "IMPOSSIBLE ! ALWAYS" deletes all columns
- Condition state might simply be omitted
- This condition state can simply be omitted

7.2. Appendix B: TERMINOLOGY

7.2.1. Main areas on the screen

7.2.2. Terminology of the decision table

7.3. Appendix C: PROLOGA FILE FORMATS

For those users who wish to interface to **Prologa**, this appendix describes the various **Prologa** file formats. Table 7-1 lists the different file types used by **Prologa** and related programs.

File-extension	Description
TAB	The internal storage form of a decision table
DEC	The Table Statement form
Only in older versions:	
EXP	The Expanded decision table
CMP	The contracted decision table
SCM	The semi-contracted decision table

Table 7-1. Main Prologa File Formats

7.3.1. The TAB and EXP Files

The TAB and EXP-formats are very similar. They contain the same information, but the EXP-format has been documented to improve its readability. We strongly recommend developers to use the TAB-file only. The EXP-file should only be used for documentation.

The following table explains the contents of these file formats.

VariableName	Meaning	Number of Lines
knum	Number of conditions in the table	1 line
anum	Number of actions in the table	1 line
ktekst[i]	Text of condition i (1 to knum)	knum lines
atekst[i]	Text of action i (1 to anum)	anum lines
bnum	Number of decision rules	1 line
tnum	Number of table columns in the expanded table	1 line
gnum	Number of columns in decision grid chart	1 line
statnum[i]	Number of states for condition i (1 to knum)	knum lines
stekst[i,j]	Text of state j (1 to Statnum[i]) of condition i (1 to knum)	Σ statnum[i] lines
btekst[i]	Decision rule in **Prologa** syntax (1 to bnum)	bnum lines
-	expanded decision table	tnum lines
-	decision rules in matrix format (decision grid)	gnum lines

Table 7-2. The contents of the TAB and EXP file formats

The EXP-format mentions all variable names within the file, the TAB-format does not. However, both contain all these variables in the order mentioned above. To get a better understanding of the

file format, print out both the TAB or the EXP file from an example you are acquainted with. Analyze this example using this appendix.

Now that the file structure has been described in general, the syntax used to represent decision rules, decision table and decision grid chart is described in other sections.

7.3.1.1. Syntax of the Decision Rules

The "natural language" elements of the specification language, as they have been explained earlier, are replaced by symbols for storage purposes. This approach has two main advantages. First, the resulting notation is more compact. Second, language becomes a problem when other language groups want to use the same program. Using symbols makes the decision rules independent of these language considerations.

The available natural language operators have been dealt with elsewhere in this manual. The following table gives a partial list of symbols that are used in **Prologa** to represent decision rules. For the complete list, see the chapter on decision rules.

?	(possibly if)	*****	(and)	**-**	(not)	/	(impossible)
:	(generally if)	**+**	(or)	\	(minus)	**@**	(all)
!	(definitely if)	**&**	(xor)	**_**	(none)	|	(only)

Table 7-3. Symbols used in decision rules and their meaning

In the decision rules, conditions are indicated by their condition number, and their states are indicated by a letter.

To make this less abstract, some examples are given, first in their symbolic, and then in their natural language form, followed by an explanation of the rule. The advanced **Prologa** user may find it interesting to know that the symbolic form can be entered directly into the **Prologa** Rule Editor as well.

Examples:

```
1:(1a*(2a+2c))
```

{1 generally if (1a and (2a or 2c))}
This rule indicates that action 1 has to be executed if state 1 of condition 1 and state 1 or state 3 of condition 2 are valid, unless another rule states otherwise.

```
4!(1b*-(2c*3c))
```

{4 definitely if (1b and not (2c and 3c))}
Here action 4 definitely has to be executed if state 2 of condition 1 and not (state 3 of condition 3 and state 3 of condition 3).

```
2?|2c
```

{2 possibly if only 2c}
Action 2 is only possible if state 3 of condition 2 is valid.

7.3.1.2. Syntax of the expanded decision table

Each line from the expanded decision table will consist of a character for each condition and for each action of the decision table. The condition character will be a letter indicating the state for which the action part of this line is applicable. The line is ended with an (im)possibility indicator.

The following tables give the list of symbols for the actions and for the impossibility-indicator of the expanded decision table.

. (empty = default)	**x** (execute action)	**-** (do not execute action)
+ (execute action unless stated otherwise)	**/** (do not execute action unless stated otherwise)	**?** (Contradiction)

Table 7-4. The list of symbols for the actions of the expanded decision table

.	(possible)	**!**	(impossible)
:	(impossible unless stated otherwise)	**x**	(action indicated with x or -)
c	(contracted = only used internally[1])		

Table 7-5. Symbols used for representing the impossibility-indicator of the expanded decision table

Examples:

```
bca...+.
```

This line corresponds to a table column where the second state of condition 1, the third state of condition 2 and the first state of condition 1 are true. The action to be executed for this table column is action 4

```
abcx-+.x
```

This line corresponds to a table column where the first state of condition 1, the second state of condition 2 and the third state of condition 3 are true. The actions to be executed for this table column are actions 1 and 3. Action 2 must certainly not be executed.

```
ccb....!
```

Corresponds to the table column for the rule / ! (1c and 2c and 3b). In natural language this means that the combination of state c of condition 1 and state c of condition 2 and state b of condition 3 is definitely impossible. `ccb....:` means that this combination is impossible, unless stated otherwise.

7.3.1.3. Syntax of the matrix format for decision rules

The matrix format for decision rules or the decision grid is another way to write the decision rules. Decision rules containing OR are split out so that all OR statements disappear. Keep in mind that the order is the same as the rule order in the original decision rules.

As for the lines of the expanded table, the rows of the decision rules matrix format consist of a character for each condition and for each action of the decision table. After this series of

1. The expanded decision table as it can be found in the TAB-file is also used internally in Prologa for representing the decision table. It is stored into the array TableA. The c-indicator for contraction is not used in the external TAB-file.

characters a reference to the corresponding decision rule is added. The characters of the condition-part indicate the states letters. The symbols for the action-part are shown in the table.

. (empty = default)	**-** (do not execute action)	**?** (possibly impossible)	**!** (impossible)
x (execute action)	**+** (execute action unless stated otherwise)	**/** (do not execute action unless stated otherwise)	**:** (impossible unless stated otherwise)

Table 7-6. Symbols used for representing rules in the decision grid chart

Examples:

```
abc..+.1
```

This row from the decision grid chart indicates that action 3 has to be executed if state a of condition 1, state b of condition 2 and state c of condition 3 are true, unless stated otherwise. This row is distilled from decision rule 1.

```
b--x...3
```

This row indicates that action 1 definitely has to be executed if state b of condition 1 is true. Which state condition 2 and 3 are in is not important.

7.3.1.4. The Holidays Example

In an earlier chapter, we have constructed the Holidays decision table. After reading this chapter, we assume that the reader is familiar with the problem. Therefore the TAB/EXP-file for this example has been printed out below, together with some comments. The comments are put in the normal type and are put between brackets. These comments do not appear in the "real" files.

```
knum : 2 {Number of conditions}
anum : 4 {Number of actions}
ktekst[1] : Age of Employee {Text for condition 1}
ktekst[2] : Years in Service {Text for condition 2}
atekst[1] : Assign 22 days {Text for action 1}
atekst[2] : 5 days extra {Text for action 2}
atekst[3] : 2 days extra {Text for action 3}
atekst[4] : 3 days extra {Text for action 4}
bnum : 6 {Number of decision rules}
tnum : 12 {Number of columns in the expanded table}
gnum : 11 {Number of lines in the decision grid}
statnum[1] : 4 {Number of condition states for condition 1}
statnum[2] : 3 {Number of condition states for condition 2}
{The following 7 lines (4 + 3) contain the text of the condition states}
stekst[1, 1] : < 18
stekst[1, 2] : 18 - < 45
stekst[1, 3] : 45 - < 60
stekst[1, 4] : >= 60
stekst[2, 1] : < 25
stekst[2, 2] : 25 - < 40
stekst[2, 3] : >= 40
{The following 6 lines (bnum) contain the decision rules in Prologa syntax}
btekst[1] : 1!#
btekst[2] : 2:1a
btekst[3] : 3:(2b+2c)+(1c+1d)
btekst[4] : 4:2c+1d
btekst[5] : /!1a*(2b+2c)
btekst[6] : /!1b*2c
```

Figure 7-1. Printout of the Holidays.exp file (variables)

```
expanded table : {contains Tnum lines (tnum= 12)}
aax+..x {if less than 18 years old then definitely 22 days + generally 5 days extra}
abx++.! {impossible combination of states}
acx+++! {impossible combination of states}
bax...x {the last x indicates that there is an action indicated with 'x'}
bbx.+.x {definitely 22 days and generally 2 days extra}
bcx.++! {impossible combination of states}
cax.+.x {This and the following lines are left as an exercise}
cbx.+.x
ccx.++x
dax.++x
dbx.++x
dcx.++x
```

Figure 7-2. (continued) Printout of the Holidays.exp file (expanded decision table)

```
decision rules in matrix format : {contains Gnum lines (tnum= 11)}
--x...1
a-.+..2
-b..+.3
-c..+.3
c-..+.3
d-..+.3
-c...+4
d-...+4
ab!!!!5
ac!!!!5
bc!!!!6
```

Figure 7-3. (continued) Printout of the Holidays.exp file (decision grid chart)

7.3.2. The CMP File (in older versions)

The CMP file represents the contracted decision table.

For each condition there is a column indication for which states the actions of the row have to be executed. If there is more than one state mentioned in such a condition-column, this has to be read as OR. If no states are mentioned, but a minus sign, then this condition is irrelevant. The different columns are connected by ANDs.

The syntax used for the action part is essentially the same as for the expanded table. The impossibility-indicator which was used in the expanded table has been omitted. The syntax is shown in the following table.

. (empty = default)	**x** (execute action)	**-** (do not execute action)
+ (execute action unless stated otherwise)	**/** (do not execute action unless stated otherwise)	**?** (Contradiction)

Table 7-7. The list of symbols for the actions of the contracted decision table

Example: Part of a contracted table :

```
a     a     -     x-..
a     b     a     x-x.
a     b     bc    x-..
a     c     -     x...
b     ab    -     .-.x
b     c     ab    ...x
b     c     c     ....
```

The fifth line would mean that action 4 has to be executed, and action 2 has not to be executed, for (1a AND (2a OR 2b)

7.3.3. The SCM File (in older versions)

The SCM file represents the semi-contracted decision table.
Every condition entry is either a single value or an irrelevancy (-). State enumerations for one condition do not occur, as opposed to the CMP file.

For each condition there is a column indication for which state the actions of the row have to be executed. Only one state is mentioned for each condition entry in a condition-column. If no states are mentioned, but a minus sign, then this condition is irrelevant. The different columns are connected by ANDs.

The syntax used for the action part is essentially the same as for the expanded table. The impossibility-indicator which was used in the expanded table has been omitted.

7.3.4. The DEC File

The DEC file stores the Dectable statement. The Dectable statement is composed from the 3 parts of a decision table and has the following structure:

```
DECTABLE
  COND   list of conditions with its states
  ACT    list of actions
  RULES  list of decision rules
END
```

Each of these elements is a numbered list, where the numbers are followed by a colon and where the different items are separated by semi-colons. For the conditions the possible states are also indicated, separated by a comma. This syntax has been inspired by Pascal. That is why the semi-colon separates the different statements. The comma separates similar elements. The numbering compares to the use of labels. The combination "`Condition : States`" represents a TYPE consisting of all possible condition values.

The syntax of the DECTABLE statement (Figure 7-4) is defined using the Backus-Naur Form (BNF), with following meta-symbols (see VANTHIENEN [86]):

::=	:	is defined as
[...]	:	optional (0 or 1 times)
{...}	:	iteration (0 or more times)

```
  <dectable statement>   ::=  DECTABLE
                               COND [ <condition-list> ; ]
                               ACT [ <action-list> ; ]
                               RULES [ <rule-list> ] END

    <condition-list>     ::=  <condition> { ; <condition> }
    <action-list>        ::=  <action> { ; <action> }
    <rule-list>          ::=  <rule>  { ; <rule> }

    <condition>          ::=  <number> <conditionname> :
                                 <state-list>
    <state-list>         ::=  <state> { , <state> }
    <action>             ::=  <serial number> <actionname>
    <rule >              ::=  <serial number> <decisionrule >

    <serial number>      ::=  <number> :

    <decisionrule >      ::=  <see decision rules>

    <actionname>         ::=  <Pascal statement>

    <conditionname>      ::=  <characterstring, without ":">
    <state>              ::=  <characterstring,
                                   without "," and ";">


with as supplementary constraint
(to be checked by the target compiler) :

      <conditionname> <state> ::=  <Pascal expression>
```

Figure 7-4. Syntax of the DECTABLE statement

Example: The Dectable file for a Tarification Problem:

```
DECTABLE
  COND 1: Distance : < 50 km, >= 50 km;
       2: Means of Transport : Car, Truck, Train, Plane;
  ACT 1: Percentage A;
      2: Percentage B;
      3: Percentage C;
  RULES 1: 1 generally if (1a and (2a or 2c));
        2: 2 generally if (1a and (2b or 2c));
        3: 3 generally if (1a and 2d);
        4: 2 generally if (1b and (2a or 2b))
END
```

Figure 7-5. Printout of a Dectable file

7.4. Appendix D: HISTORY OF DECISION TABLES AND PROLOGA

7.4.1. Evolution of decision table research and practice

Though the decision table still looks almost the same as in the early days of its first developments, some profound changes can be noted concerning the contents and the application field of the decision table technique. This can be seen from the stages in the history of decision tables (e.g. POLLACK, HICKS & HARRISON [71] and MAES [81]).

Originally decision tables were used to construct the logic of programs, but more recent developments show that the application field is much larger. Also the objective has changed : the emphasis has moved towards the power of the decision table to represent complex decision situations in a simple manner and to check for consistency and completeness.

It therefore seems appropriate, without proceeding towards a detailed subdivision into distinct stages, to situate the main points of attention in the evolution of decision table research and development (Figure 7-6).

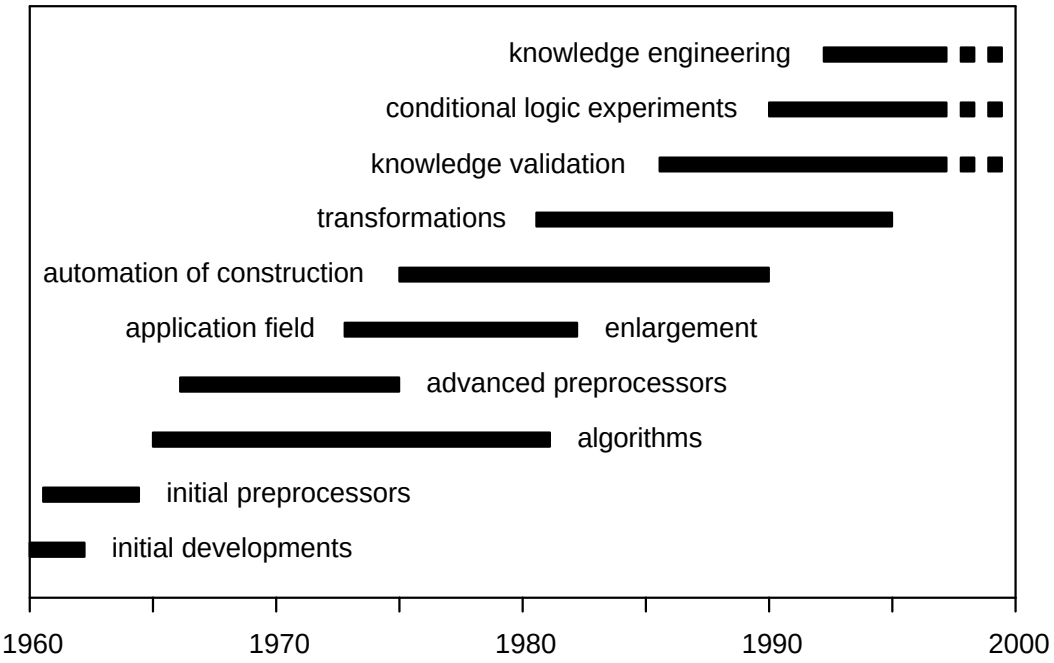


Figure 7-6. Evolution of the decision table technique

- The use of decision tables was first reported in 1957, in data processing applications (NCC [70]). Because of its representational capabilities, the decision table was introduced as a structured alternative to classical flowcharting.
  The ability to represent conditional logical expressions in a readable manner and the ease of adaptation and consistency checking are considered as a solution to the problem of increasing program complexity.

A number of specific languages and initial preprocessors are developed rather soon (1961-1962), to convert the two-dimensional decision table into common program code. Due in part to the limited efficiency of these simple processors, the increasing interest does not lead to general acceptance in the world of programming.

- This gives raise to the enlarged attention (from 1965 onwards) to the optimization of the conversion process, soon followed by the emanation of more powerful commercial preprocessors.

  In this era (between 1965 and 1980), a lot of effort is devoted to the (theoretical) conversion of decision tables into efficient computer programs, leading to a growing list of *conversion algorithms*. These algorithms gradually make it possible to obtain an optimal program structure (with respect to execution time) starting from (limited entry) decision tables. The more important of these algorithms are, in chronological order : POLLACK [65], REINWALD & SOLAND [66], KING [66], MUTUKRISHNAN & RAJARAMAN [70], SHWAYDER [71], VERHELST [72], BAYES [73], GANAPATHY & RAJARAMAN [74], SHWAYDER [74], SMILLIE & SHAVE [75], SHUMACHER & SEVCIK [76], LEW [78], MARTELLI & MONTANARI [78], SETHI & CHATTERJEE [80], PAPAKONSTANTINOU [80]. For a description of the evolution and the results of these algorithms, see POOCH [74] and VERHELST [80].

  The improved conversion algorithms lead to a new generation of *advanced preprocessors*, which do not only provide for program conversion, but also pay attention to various additional functions, testing features, compatibility with other generators, etc. (McDANIEL [70], MAES [81]).

  The development of new algorithms and preprocessors silently reaches an end about 1975 (except for some theoretical results up to 1980).
  It is however not a coincidence that the diminishing interest in preprocessors and, later on, also in conversion algorithms kept pace with the birth of the *structured programming* concept (DAHL, DIJKSTRA & HOARE [72], WARNIER [74], JACKSON [75], McGOWAN & KELLY [75], MEYERS [75]). The continuing improvements to the area of program conversion gradually offered the solution to a wrong, or at least, less and less relevant problem (see e.g. CHVALOVSKY [76] : "*Problems with Decision Tables*"), because structured programming is already able to achieve a considerable reduction in program complexity.
  It is e.g. no use trying to fit iterations and sequences into the strict decision table format and then to apply an optimal table conversion algorithm, as these structures can easily and efficiently be implemented in a structured language (the classical file merging problem is a typical example here, see e.g. GILDERSLEEVE [75] versus JACKSON [75]).
  These considerations, however, do not imply that the decision table technique would be obsolete or incompatible with structured programming. Well-defined application of decision tables would act not as a substitute, but as an extension to structured programming control structures (VERHELST [80]).

  But the diminishing interest in preprocessors and algorithms not only results from this change in application field. Even where the use of decision tables is possible or recommended, its practical implementation still seems to cause some problems. The reason is that, focusing on compilers and algorithms, the existence of the decision table itself has always been assumed, but few or no attention was paid to the process of constructing good decision tables, which does not constitute a trivial task.

- While the application of decision tables in computer programming is reduced to the selection construct itself, the application area of the decision table technique is enlarged towards other domains involving procedural decision situations.
  Its ability to represent logically complex situations in a readable manner and to check them for consistency and completeness, is not limited to the world of programming.
  In this era, the application field of decision tables is gradually extended to various other areas with logical complexity : information systems design, law and regulations, analysis of

specifications, structuring of management decisions, etc. (see e.g. McDANIEL [70], VERHELST [80], MAES [81], CODASYL [82]).
The need for optimal program conversion, if already relevant, is not (yet) present here.

- The rise of the decision table as a means of structuring and communication, and the increasing attention to the construction process (instead of the efficiency of conversion), shows the need for structured development methodologies and *computer support* for the construction of decision tables (VERHELST [69], VIEWEG [73], JOHNSON [74], VERHELST [80], MAES [81], WELLAND [81], CODASYL [82]).

- With the introduction of the computer into the construction process (and, more generally, into the program specification and generation area), there is a growing need for various automatic *transformations* and manipulations.
  This does not only refer to the decision table itself : expansion and consolidation, factoring and contraction, limited vs. extended entry conversion, reordering, ... (see e.g. CHENG & RABIN [76], CODASYL [82], SRINIVASAN [83]).
  The transformations, however, are not limited to the decision table technique, as its representational and other advantages link it to other similar areas with logical complexity : optimal evaluation of queries (PAPAKONSTANTINOU [82]), complexity measures of flowcharts (MAES [81], LEW [82]), classification problems (MORET [82]), correctness proofs (LEW [84]).

- The rise of rule based expert systems and the emerging problems of validation have led to the use of decision tables (or similar techniques) in knowledge acquisition, representation and validation (SUWA, SCOTT & SHORTLIFFE [84], SCHNEIDER [85], VANTHIENEN [86]).

7.4.2. Twenty years of research on automation of Decision Tables at K.U.Leuven

7.4.2.1. PRODEMO/80

The essentials of PRODEMO, PROcedural DEcision MOdeling (further called PRODEMO/80) were started by R. MAES and offered the possibility to construct an expanded decision table from a list of conditions, condition states, actions and decision rules.
The PRODEMO system introduced some new concepts in the area of decision table automation: emphasis on modeling, not program generation; extended condition-entries; problem-oriented specifications (rules); an interactive environment.

7.4.2.2. PRODEMO/82

Starting from the first version, a lot of changes and additions were worked out within the scope of an I.C.M research project to elaborate the features of the system with new functions and to enhance the flexibility and the efficiency.
Those changes were documented in VANTHIENEN (82c) and formed the final version of PRODEMO (called PRODEMO/82), described in MAES & VANTHIENEN (81b), MAES, VANTHIENEN & VERHELST (81), MAES (81) and CLEMENT & STROOBANTS (82).
Numerous additional elements were developed : table layout, full editing, contradiction control, V&V diagnosis, table options, table contraction, optimal condition order, export options, decision making, table structures.

The strength of PRODEMO was also its weakness : the use of the system required special equipment (CDC PLATO terminal) and continuous connection to the telecommunication network, which made its use very expensive. This drawback and the availability of a stand-alone PLATO workstation caused the conversion of the whole system.

7.4.2.3. MicroPRODEMO

This conversion was executed by W. STROOBANTS and resulted in 1982 in MICROPRODEMO (CLEMENT & STROOBANTS (82)), with similar possibilities and a complete independence concerning the use of the system.

The problem of the special equipment was not yet solved. The transfer to other computers was impossible because of the powerful graphic and didactic orientation of the PLATO software. This limitation in transferability, the non-structuring of the TUTOR language and the lack of non-proprietary development facilities on MICROPLATO gave rise to restart new developments in another environment.

7.4.2.4. PROLOGA v1/86 (DOS)

As the CDC 110 MICROPLATO station was also a microcomputer (with CP/M), it was decided in 1982 to restart from scratch in a more universal environment and programming language (Pascal/M). The following requirements and implementation decisions therefore were taken into consideration when developing the first version of **Prologa** :

. The programming language must be universal and structured and also offer facilities for modular and reliable software development (local variables, recursive data structures).
. The software must be easily transferable to other configurations and may only contain standard elements without reference to equipment dependent features such as graphic facilities, screen dimensions, special keys.
. Functions not belonging to the heart of PRODEMO were pushed down to the operating system (the management of stored tables).
. It must be possible to exploit the system on a conventional microcomputer. Because of this, only the essential elements could be retained.

Because of the power of the programming language, almost all functions could be implemented in an easier and more standard way and, after some experiments in UCSD Pascal on Apple II, the system ended up on the IBM PC in Turbo Pascal.

7.4.2.5. PROLOGA v2/92 (DOS)

Between 1986 and 1992 the system was continuously elaborated, reflecting the increasing features of Turbo Pascal and the personal computer environment, which resulted in a second version of **Prologa**.

The basic restrictions which were imposed while building the original **Prologa** (memory limitations, limited development environment) were continuously removed as new language features were introduced (abstract data types, separate compilation, overlays, units, and later objects).

Also the user interface of the tool was completely redesigned to correspond to current PC standards (MERLEVEDE[2]). A specialized toolbox was used to add a menu system, context sensitive help, pop-up windows. However, we did not yet opt for a graphical user interface to keep the equipment requirements a low as possible.

2. MERLEVEDE, P. [90], *Praktijkvoorbeeld van implementatie van de Common User Access, Ontwikkeling van een user-interface voor Prologa*, Dissertation, K.U.Leuven, Dept. Applied Econ., 1990, 67 pp.

7.4.2.6. PROLOGA v3/97-v5/99 (Windows)

Starting in 94 the tool was (again) rebuilt from scratch using Borland Delphi, in order to obtain two major objectives:

- Object orientation
- Windows Graphical User Interface

The basic table data structures and operations were reused, but the user interface and the tool architecture were entirely new. Moving to Delphi 2.0 (**Prologa** v4), 3.0 and 4.0 (**Prologa** v5) in 96, 97, 99 allowed to deal with most of the traditional memory limitations and include numerous fundamental enhancements.

8. Bibliography

BRATKO, I. & MICHIE, D. [87], *Some Comments on Rule Induction*, Knowledge Engineering Review, Vol. 2, 1987, pp. 65-67.

CODASYL [82], *A modern appraisal of decision tables*, Report of the Decision Table Task Group, ACM, New York, 1982.

HAZEVOETS, F., VANHOUTTE, B., VANTHIENEN, J. [90], *An Expert System Interface for Consultation of Decision Table Systems*, Intl Conf. on Data Base and Expert Systems Applications, Vienna, 29-31/8/90.

HURLEY, R.B. [83], *Decision Tables in Software Engineering*, Van Nostrand Reinhold Company Inc., New York, 1983, 164 pp.

LONDON, K. [72], *Decision Tables*, Auerbach Publishers Inc., Princeton, 1972, 205 pp.

MAES, R. [81], *Bijdrage tot een Kritische Herwaardering van de Beslissingstabellentechniek*, Doctoral Dissertation, K.U.Leuven, Faculteit der Toegepaste Wetenschappen, 1981, 397 pp.

MAES, R., VANTHIENEN, J., VERHELST, M. [81], *Procedural decision support through the use of PRODEMO*, Proc. Second Int. Conf. on Information Systems, Cambridge (Mass.), December 7-9, 1981, pp. 135-152.

MAES, R., VANTHIENEN, J., VERHELST, M. [82], *Practical experiences with the procedural decision modeling system*, Proc. Joint IFIP WG 8.3/IIASA Working Conference on Processes and Tools for Decision Support, Laxenburg (Austria), July 19-21, 1982, pp. 139-154.

MERLEVEDE, P. & VANTHIENEN, J., [91], *A Structured Approach to Formalization and Validation of Knowledge*, IEEE/ACM International Conference on Developing and Managing Expert System Programs, Washington, DC, 30/9-2/10/91, pp. 149-158.

MONTALBANO, M. [74], *Decision Tables*, Science Research Associates, Inc., Chicago, 1974, 191 pp.

POLLACK, S., HICKS, H., HARRISON, W. [71], *Decision Tables : Theory and Practice*, John Wiley & Sons, Inc., New York, 1971, 179 pp.

VANTHIENEN, J. [86], *Automatiseringsaspecten van de specificatie, constructie en manipulatie van beslissingstabellen*, Doctoral Dissertation, K.U.Leuven, Dept. Applied Econ., 1986, 378 pp.

VANTHIENEN, J. [88], *Een moderne kijk op beslissingstabellen*, Informatie, December 1988, pp. 912-937.

VANTHIENEN, J. [90], *Development of an Expert System Interface for Consultation of Decision Table Systems*, 31st G.U.I.D.E. Spring Conference, Application Development Productivity, Bordeaux, 29/5-1/6/1990.

VANTHIENEN J., *Knowledge Acquisition and Validation Using a Decision Table Engineering Workbench*, The World Congress on Expert Systems, Orlando (Florida), 16-19/12/91.

VERHELST, M. [80], *De praktijk van beslissingstabellen*, Kluwer, Deventer/Antwerpen, 1980, 175 pp.

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